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THE UPTHRUST OF THE SALT MASSES OF GERMANY[1]

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ABSTRACT

The Zechstein salt deposits of middle and northern Germany were laid down in a sinking basin in which sinking came to an end during the Jurassic, except in northern Germany, where it persisted into the late Tertiary. The beds deposited in this basin were involved in the Saxon mountain-building movements, which contrast with the older, Variscan movements in being intermediate in character between folding and block faulting. The Saxon movements were periodic and not continuous. That the movements were due to compressive thrust is shown by the fact that the "horsts" were uplifted.

The salt bodies are found in the form of "salt beds," "salt anticlines," and "salt stocks." "Salt anticlines" are normal anticlines both in the form and inner structure of the salt and in the structure of the sedimentary cover. The "salt stocks" are strongly folded, subcircular to elongated masses of salt which are upthrust into faulted rather than folded adjacent formations.

The main theories proposed to explain the upthrust of the salt are three: Lachmann's "atectonic" theory, the "isostatic" theory, and the theory of upthrust by lateral thrust. Lachmann's "atectonic" theory of upthrust of the salt by an inherent autoplastic force is no longer current. The formation of the salt anticlines by the compressive thrust of the Saxon orogenic movements is very generally accepted by German geologists. But as there is every gradation in form between the characteristic salt anticline and characteristic salt stock, as the gradation from one to the other can be followed on the same anticlinal axis, and as with a rare exception the periods of movement in the salt stocks coincide with the periods of the Saxon orogenic movements, it seems reasonable to believe that all have been caused by the same force. The difference in the resulting forms is due rather to the difference in the materials acted upon than to difference in the forces acting. The salt is more plastic and therefore more mobile than the ordinary sedimentary rocks, and is therefore the more easily deformed. Under intensive deformation, it advances far ahead of the other rocks, and thus a salt stock is the extreme form of an anticlinal core. The tectonics of salt upthrust are therefore a phase of the tectonics of mobile materials and are intermediate between the normal tectonics of folding and the tectonics of magmatic intrusion.

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[1] Translated from the German by Donald C. Barton.

THE FORMATION AND SECULAR SINKING OF THE ZECHSTEIN SALT

The folding of the Variscan mountain system which traversed middle Europe in the later Paleozoic was succeeded by depression which prepared a broad basin into which the sea penetrated at the beginning of Zechstein time. The extent of this sea in German territory can be seen from Figure 1. Toward the northwest it stretched

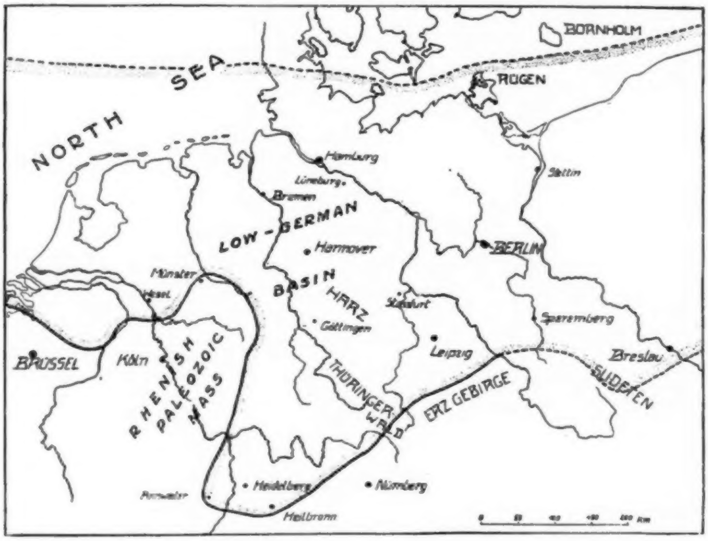

FIG. 1.—Map showing the probable extent of the German Zechstein Sea

to middle England; toward the east it had a broad connection with the Russian late Permian basin. This Zechstein sea has left behind the most widely extended salt deposit that has ever been formed in the course of the earth's history. A valuable feature of this salt deposit is its well-known succession of beds of potash salts, which were deposited principally in the German portion of the great basin, in general in a single series, but in certain areas, in two series.

The Zechstein was followed by the Trias; the great basin, which had become land during the formation of the salt deposits at the end

of the Zechstein, broadened into the basin of the Germanic Trias, and within those extended boundaries the sinking movement continued. Buntsandstein, Muschelkalk and Keuper were deposited above the Zechstein salts, which sank correspondingly. Even in the older Jurassic, this sinking process continued generally, but began to be differentiated. In the southern and middle portion of the former Zechstein area, the sinking gradually came to an end; while in the north, in the "North German basin," it continued. There, Dogger and Malm, Cretaceous and Tertiary were deposited in great thickness, although farther south, in the area which formed the "Middle German continent" of that time, these beds are wholly or almost wholly lacking. In the north the salt sank many thousands of meters below the surface; in many portions of the "North German basin," the lower Cretaceous alone has a thickness of over a thousand meters. The great thickness of this sedimentation indicates the "North German basin" especially, as well as the Zechstein-Triassic basin in general, as a geosyncline, if by "geosyncline" we understand broadly a secularly sinking area of sedimentation without regard to the character of the sedimentation which took place in it, without regard to its shape, and without regard to the form of the mountain-building which affected it. By the sinking that has been described and by burial under an ever increasing mass of sediments, the salt reached, in the course of time, warmer and warmer regions. The salt compounds, formed at the temperature of the Zechstein times, in part became no longer stable; varied thermo-metamorphism set in (21, 23)[1] and changed the original composition and structure; thus the paragenesis, sylvinite-kieserite, which as *Hartsalz* is widely extended through the German salt deposits and which can form only above 72° C., can be explained according to Arrhenius' theory (2, 3) as the result of thermo-metamorphism consequent upon the geosynclinal sinking of the Zechstein salt. From the thickness of the overlying sedimentary cover of that time and from the geothermal gradiant, it is possible to calculate at about what time the *Hartsalz* of the various portions of the Germanic basin formed from the original salt compounds. Beneath the present southern Hannover area this must have happened about during Lias times.

[1] Numbers in parentheses refer to the bibliography at the end of the paper.

THE SAXON MOUNTAIN-BUILDING OF GERMANY, THE FRAME OF THE TECTONIC DEFORMATION OF THE SALT MASSES

The *downward movement* of the salt was of varying intensity. In the "North German basin" it carried the salt several thousand meters below sea level. In Middle Germany, in those areas which since Dogger times have belonged to the Middle German continent, it was of far less intensity.

The *uplift* of the salt to the levels at which wells and shafts now reach it stands in the closest dependence upon the "Saxon" mountain-building.

Two great mountain systems are to be distinguished in the subsurface structure of Germany. The older, the Variscan, has already been mentioned; it was obliterated at the end of the Paleozoic. The younger is the Saxon, which in form, is widely different from the older. If the older can be said to be true folding ("Alpine type" of mountain-building), the younger can be said to have expressed itself in faulting ("Germanic type" of mountain-building) with subordinate folding. Yet in the "block terrane" of Germany it is possible to recognize an arrangement of structure along certain lines of uplift and depression, just as in folded mountains the strata are elevated along certain lines (anticlinal axes) and depressed along others (synclinal axes). The Saxon mountain-building consequently has as its basis a certain fold plan in which the folds, in contrast to the normal type of folding, are allied in strong degree, already *in statu nascendi*, with faults (compare Fig. 2). They are spoken of in this sense as "fault folds" (Bruchfalten), which in the series of tectonic forms take an intermediate position between true folds and block faults.

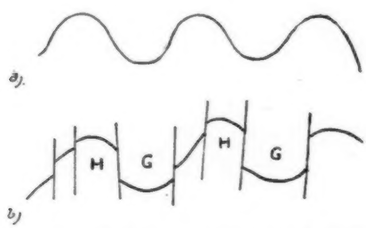

FIG. 2.—Diagrammatic sketch illustrating: (*a*) normal folding, and (*b*) fault-folding.

The conception that lateral pressure had created the Saxon "fault-folding" was strongly contested up to about ten years ago, but at present it seems to have found general acceptance among the

German geologists. The deviation of the forms from the normal forms of folding, especially through the cutting of the folds by a host of faults, may be explained by the increased stability which the subsurface had gained through the Variscan folding and by the magmatic-volcanic processes which took place with that folding and in consequence of it.

A normal fold of folded terrane and a fault-fold of the German block terrane are illustrated in Figure 2. In fault-folding, the horst (*H*) corresponds to the anticline of the normal folding, and the graben (*G*) corresponds to the syncline.

The Saxon mountain-building favored the southeast-northwest (Hercynian) direction. The Rhenish, north-south, direction also is strongly in evidence in a broad zone which lies east of the Rhenish mass of Paleozoic schists, in prolongation of the upper Rhine graben, and which extends far to the north past Hannover and Lüneburg into the area of the lower Elbe. A phenomenon which is of great significance in the explanation of the occurrences of the salt is abundantly recognizable: the intersection of the axes of elevation and depression of Hercynian and of Rhenish directions, respectively, give rise to interference phenomena, as, for example, an especially strong uplift where two zones of uplift cross, or an especially strong depression of the subsurface where two lines of depression cross. That the Saxon orogenesis, like orogenesis in general, took place in individual periods, broken by long periods of relative quiescence in which exclusively movements of epeirogenic character set in, is no longer contested from any side. These periods are recognized by the demonstrable angular unconformities within the sedimentary series of Germany. It thereby becomes recognizable that it is a question of the same periods which elsewhere in the world are evident in the late Mesozoic–Early Cenozoic time. Up to perhaps twenty years ago, it was believed that there were not more than two periods which came in the Miocene, but evidence has now been obtained of other, especially older, mountain-building, of which the earliest, the Cimmerian, took place in three subperiods at the end of the Jurassic. It corresponds to the Pacific revolution in America. Other periods followed in the Cretaceous, and a very important movement took place at the end of the Cretaceous and the beginning of the Tertiary, con-

temporaneously perhaps with the Laramide Revolution of North America. New orogenic movements set in at the end of the Eocene and Oligocene; several followed even in the late Tertiary; and in fact weak echos are evident in the Quaternary. In the orogenic periods, the beds which had gradually sunk during the preceding time and which had been correspondingly deeply buried under sediments were again moved upward in broad zones in the formation of a fault-fold system. Downward movement, however, soon set in again in many places, and after the fault-folds had been planed off by a denudation, they were covered anew. The renewed movement of depression then continued until another orogenic period brought about yet another movement of uplift. Thus it is possible to recognize in the North-German basin a repeated alternation of long-continued depression broken in certain zones and along certain lines by spontaneous upward movement.

James Hall recognized in North America as much as sixty-five years ago that folding sets in where the sediments are very thick that is, to use Dana's expression, in geosynclines, while the up-arched areas in which there was little or no sedimentation are spared by the folding. This fundamental law of mountain-building is proved true also among the lesser structural features of the Saxon areas. Where sedimentation did not take place after Variscan times or was small in amount, that is, where the sinking of the ground soon came to a stop, we have only weak Saxon mountain-building. Conversely, the folding was most intensive where, after the Variscan folding, the subsurface sank the deepest, and where, correspondingly, the younger sediments were deposited in the greatest thickness. Quite in the sense or in the extension of Hall's thought, in fact, it is possible to recognize in individual basins, as, for example, in the so-called sub-Hercynian basin, increases in the intensity of folding with increase in depth of the basin.

Since the upward movement of the salt masses is most closely connected with the Saxon fault-folding, and especially since tension phenomena are not lacking within the fault-folded zone, it may be asked whether the explanation of the fault-folds by lateral thrust is to be accepted unconditionally.

Edward Suess, as a matter of fact, in *The Face of the Earth*, wished

to explain the German "block terrane" by differential downward movement according to the example of horsts and grabens. But subsequently it has become possible to divide the Mesozoic-Cenozoic tectonic processes into individual periods, and by comparison of the successive steps to win a deeper insight into the nature of the processes. Especially it has been shown that in the orogenic periods in which the faults and fault-folds arose, the rock masses affected in no case moved downward but instead moved upward. Beds which before the orogenic movements had lain deep below sea level, after those movements were exposed to sub-aerial denudation as part of the fault-fold system which had arisen in the meantime. Following peneplanation, the area was soon again covered by a new transgression. This problem, which is so important for a comprehensive conception of the Saxon mountain-building, was discussed more in detail by the author in 1911 (32).

In this Saxon folding the terrane which was being changed over into a fault-fold mountain system was moved upward and, in fact, differentially, just as in true folding a differential upward movement takes place, stronger in the anticlines and somewhat weaker in the synclines. The graben in a fault-fold system has not sunk, but has been raised less than the horst, just as, in folded systems, the beds in the syncline have been raised less than those in the anticline. But as yet it has been possible to recognize outside of lateral pressure scarcely any force which could move a block system differentially upward.

THE PRESENT FORMS OF OCCURRENCE OF THE SALT MASSES OF THE GERMAN TERRANE

The outer form and inner structure of the salt masses are intimately related to one another, and in this relationship we recognize everywhere a more intense deformation of the salt than of the adjacent formations and cover. This effect without doubt is the result of the high plasticity of the salt. Even at normal temperature and normal pressure the salt has a relatively high plasticity, which increases extraordinarily with increasing pressure and increasing temperature, as has been shown experimentally by Milch (19) in regard to the temperature and by F. Rinne (20, 21) in regard to pressure.

The following three main types can be distinguished among the various forms of the German salt deposits:

a) Salt beds (*Salztafeln*)

b) Salt anticlines (*Salzsättel*)

c) Salt stocks (*Salzstöcke*)

Salt beds.—The salt beds (see Fig. 3*a*) are horizontally lying or gently inclined platelike masses of salt formations regularly intercalated between the middle Zechstein below and the Bunstandstein above. Within the salt beds the individual strata in general are regularly concordant with one another and with the overlying and underlying formations; yet abundant irregularities and folds are met with which are not present in the overlying and underlying strata. Even overturned folds projecting far out, with salt strata thinning and thickening, are encountered in many places in the salt beds; such phenomena are all the more surprising in view of the great regularity of the bedding of the overlying Buntsandstein. The "salt beds" are present south of the Harz (south Harz area) and west of the Thuringian Forest (Werra area).

Salt anticlines.—The salt anticlines (Fig. 3*b*) are up-archings which have affected the salt and the overlying beds in somewhat the same degree, so that the salt is the core of an anticlinally folded complex of Buntsandstein beds. Although there are many types of special complications (21, Tafel 11), the bedding within the salt mass in general is anticlinal. If the salt core of the anticline has approached the surface and has come in contact with the ground water, a "salt table" (see below) is developed at the top of the salt core as the result of subsurface solution of the salt (Fig. 3*c*). As a result of such solution, the overlying beds sink and in certain areas of middle Hannover, the Tertiary is found preserved in "solution-grabens" above the salt, while off the salt, where the downward movement did not take place, it has been more or less completely removed by denudation.

Salt stocks.—It is in the German salt stock that the American geologist is especially interested, for in the first place the salt stocks are very similar in their general appearance to the salt domes of Texas and Louisiana, and in the second place oil is found in many places on their flank zones, as in Texas and Louisiana (Wietze-

Steinförde, Hänigsen, Oelheim). Their genesis has been the most disputed question of all the German salt occurrences. They show special peculiarities as to: (1) their outer form and especially their

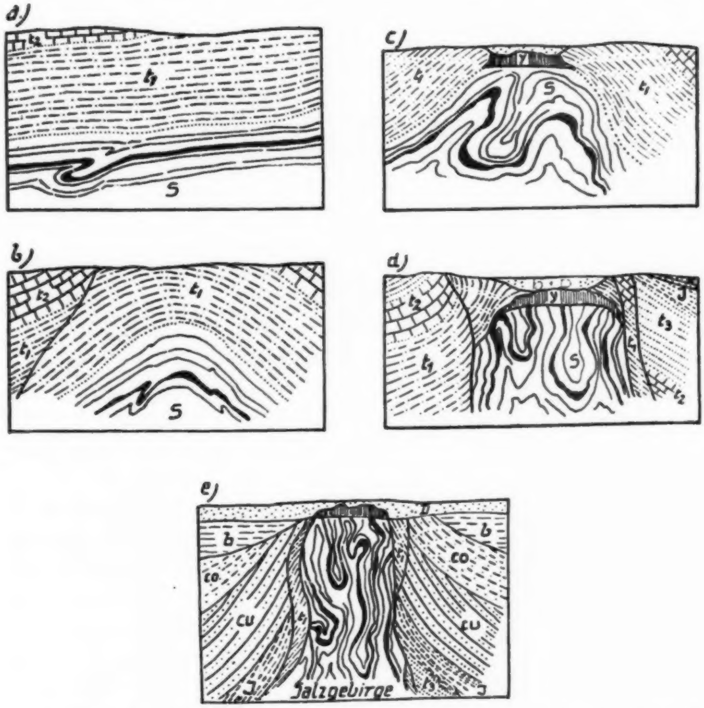

FIG. 3.—Tectonic forms of the occurrence of the German salt deposits: (*a*) "salt bed," south of the Harz; (*b*) salt anticline, South Hannover; (*c*) salt anticlines with "salt table," Hildesheim; (*d*) transition between salt anticline and salt stock, Benthe; (*e*) salt stock, North Hannover. Stratigraphic legend: *D*, Diluvium; *b*, Tertiary; *CO*, Upper Cretaceous; *J*, Jurassic; t_3, Upper Triassic (Keuper); t_2, Middle Triassic (Muschelkalk); t_1 Lower Triassic (Buntsandstein); *Y*, Residual gypsum cap; *S*, Salt formations with potash beds in heavy black lines; *CU*, Lower Cretaceous

position with reference to the adjacent formations, and (2) their inner structure.

The salt stocks are salt masses of circular, elliptical, elongated, or

quite irregular plan, rising from great depths where in general they still have their roots. They no longer stand in the normal relation to their original cover, the Buntsandstein, but usually have penetrated into far younger beds, as for example into Cretaceous and Tertiary formations. Triassic and Jurassic beds are lacking on the salt stocks in extreme cases or are present as intermediate blocks between the salt and the younger adjacent formations. The salt is cut off above by a salt table (6) which is a more or less flat plane, formed by subsurface solution. The salt table in Hannover, the classic land of the salt stock, lies at a depth of around one hundred to two hundred meters (29). It is covered by residual gypsum (gyp cap), which is a residual formation resulting from the anhydrite originally held in the now dissolved salt.

The flanks of the salt stocks are in general extremely steep, but in many cases have gentle dips to great depths. It is observed in many cases that the flank of the salt stock bends in a "swan's neck" curve, and in a few cases this curve is present on all sides, so that the salt constricts in funnel shape downward; in extreme cases the salt stock may terminate in a point downward and stand as a great isolated salt drop floating in younger formations.

The inner structure of these salt stocks has become known in detail through potash-mining. In general, intensive folding is revealed, often of the isoclinal type, which expresses itself in a multiple repetition of salt beds in the same profile (see Fig. 4). In that folding, the single beds undergo mechanical thickening and thinning such as we know in the Alpine types of folding; such phenomena are most easily recognized through the potash beds; in the limbs of many folds, these show supernormal thicknesses, although in other places they have thinned until they are unworkable. Thus in the Riedel shaft (north Hannover), a series of salt beds which normally possess a thickness of sixty meters is only two meters thick in places, yet each individual bed is discernible though proportionately thinned (28). In rock salt which shows "yearly rings" (*Jahresringe*) with a greater or lesser content of anhydrite, Seidl (25, 26) has differentiated "compression salt" (*Stausalz*) and "tension salt" (*Zerrsalz*). In the compression salt, the yearly rings have separated from one another, while on the contrary in the tension salt they have approached one another, since

the salt has been very greatly squeezed. The salt formations of the Zechstein in fact comprise beds of varying plasticity; carnallite is less plastic than the rock salt (21), and least plastic of all is the anhydrite, which occurs in thin beds as well as in the "main" anhydrite, with a thickness of forty to fifty meters. The "main" anhydrite,

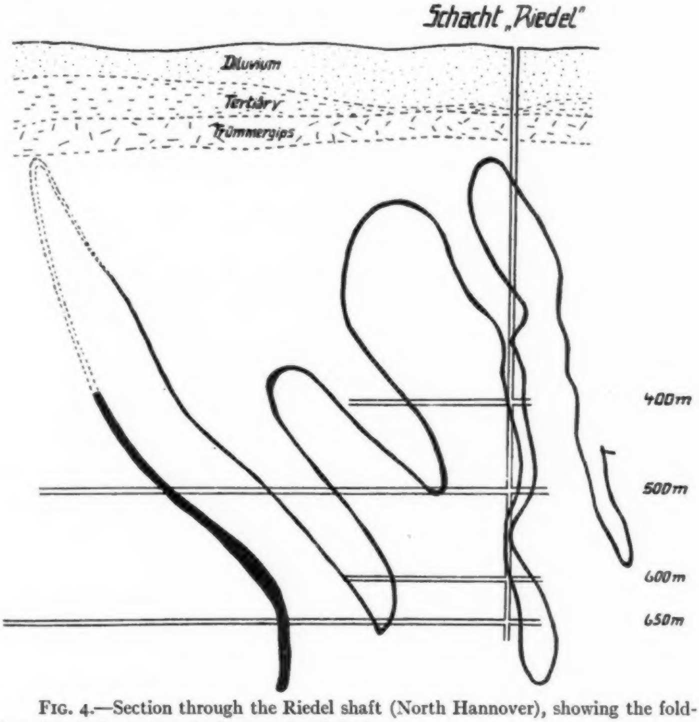

FIG. 4.—Section through the Riedel shaft (North Hannover), showing the folding of a single stratum in the potash salt beds.

(*Hauptanhydrit*) and in part also the "gray salt clay" (*Grauer salzton*) that accompanies it, show quite a different reaction to the tectonic forces from the rock salt and potash salt. The "main" anhydrite in most cases does not take part in the intensive folding, and does not deform plasticly like the salt, but in many cases is shattered. There arises therefore the form which has been designated by Seidl (25, 26)

in correspondence with Mrazec as "diapir" folds, in which the more mobile salt wells up through the gaps in the "main" anhydrite.

Although the salt shows the typical phenomena of folded formations, the surrounding younger beds, everything considered, are displaced more after the type of block faulting.

THEORIES OF EXPLANATION OF THE UPTHRUST OF THE SALT

Atectonic upthrust of the salt masses.—The theory of upthrust of the salt independently of the normal tectonic forces has been advocated in Germany especially by R. Lachmann (12–18). The peculiarity of the phenomena which have just been described in their larger phases led him to the conception that any explanation through the normal theories of tectonics is not possible and that in the upward movement and deformation of the salt masses, therefore, quite other forces must have acted than those which deformed the adjacent rocks. He therefore spoke of an "autoplastic" upthrust of the salt masses, that is, an upthrust of the salt by forces which are located substantially in the salt. He had an idea especially of a molecular movement of dissolved material from zones of strong pressure to zones of lesser pressure, that is, from the great depths toward the surface. Through such processes of solution and recrystallization, the salt was supposed to have broken through the earth's crust as an ulcer breaks through the skin of an animal; hence Lachmann's designation, "salt eczeme." Lachmann did a very great service in having aroused discussion over many questions of the occurrence of the salt, but his theory lacked a satisfactory physical explanation for the assumed autoplasticity of the salt masses.

Isostatic upthrust of the salt masses.—Although isostasy has been awarded in Europe, and especially in Germany, only a secondary significance as the cause of the present structural relations of sedimentary beds, it has enjoyed more common acceptance as the cause of salt upthrust. E. Harbort (8–10) especially recognized the motive force for at least a part of the salt upthrust in the loading of the salt masses that already were present in a strongly plastic condition at great depth, and that therefore were already capable of being upthrust. According to Harbort, who did not misunderstand the posi-

tion of the salt masses in the cores of the anticlines in the province of Saxony, in the sub-Hercynian basin, in southern Hannover, etc., the upward movement and the folding of the salt in the older Saxon periods was a folding phenomenon which affected the salt masses more strongly than the less mobile adjacent formations; but according to him, the latest upward movements at least are to be explained through the loading of the deeply buried salt by the younger sedimentary masses and the subsequent passage of the salt upward along fractures after the manner of a magma. Prominent students of salt domes such as Beyschlag (4), Seidl (26), and to a certain extent also Rinne (23–24) share Harbort's conception. Lachmann also approaches very near to it in leaning toward Arrhenius' (2, 3) ideas. Interested in the salt dome problems by Lachmann, who hoped to get from him a physical explanation of the atectonic upthrust of the salt, Arrhenius attributed the upward movement of the salt mass to its lesser specific gravity, compared with that of the normal rocks. He seems to have assumed that the salt stocks in general are surrounded by wet soft clay or even by ground water.

Upthrust of the salt masses through folding.—The chief exponent of the conception that in the upward movement of the salt the same forces have been active as in the adjacent formations, that is, in last analysis, lateral compression acting in the earth's depths, is the author (27, 29–31). In this theory, the cause of the peculiarities of the tectonic forms of the salt masses lies exclusively in the peculiarities of the materials in question. It is not that different forces have acted in the salt and in the adjacent formations, but rather that the same forces have worked differently, and they have worked differently because of the different character of the materials.

THE INTERPRETATION OF THE SALT UPTHRUST IN THE FRAME OF THE SAXON STRUCTURE AS A WHOLE

Everything considered, the theory of atectonic change of form of the salt formations can be regarded as overthrown. In opposition to one another there remain therefore to be evaluated the theories of isostatic upthrust and upthrust through folding.

The continuity of the forms of occurrence of the German salt deposits.

—Unquestionably one main error has repeatedly been made in the investigations and discussions of the German salt bodies, that is, that to account satisfactorily for a single object or a single type will solve a problem which in the last analysis must find its explanation in the consideration of the totality of the phenomena. Scientific controversy in Germany turned in the main around the salt stocks ("salt pillars," "salt eczemes"), although there is a certain agreement to the effect that the salt *anticlines* were the result of the lateral pressure that had affected the other rocks of the German terrane. But one may not regard the salt stocks apart from the other occurrences of the salt, especially the salt anticlines. The salt stocks are connected with the salt anticlines: (1) as types of phenomena; (2) in space.

The connection as types of phenomena consists of a complete series of intermediate forms between the typical salt anticline and the typical salt stock, not only in regard to position in reference to the adjacent formations, but also as to the yet more complicated inner structure (see Fig. 3). Certainly an anticline as we find it at Salzderhelden, in south Hannover, where the salt shows no great special complications in its inner structure and where it is regularly covered and mantled by the older Triassic as the core of an anticline, is immensely different from a typical salt stock of the Lüneburg type, where a huge pillar of salt sticks up in the middle of Cretaceous and Tertiary beds, even lacking, in some cases, the intermediate beds of Triassic and Jurassic, and where there prevails a folded structure which is comparable to the Alpine types of folding. But between these two there stand other forms, anticlines in which the salt core has experienced a somewhat intensified upward movement so that perhaps it is mantled in some parts by Buntsandstein but in other parts by much younger beds, in which, however, the anticlinal character is visible both in the inner structure as well as in the anticlinal structure of the adjacent formations. Such intermediate forms are met, for example, east and west of the city of Hannover. The series of the forms of the salt bodies can be begun with the flat salt beds, which can be thought of as derived from salt anticlines by the decrease of the dip of the wings, such a series, from the salt bed through the salt anticline to the salt stock, is represented in Figure 3.

If these natural relationships had been kept more sharply in view, much misdirected effort in working out the tectonics of the salt deposits would have been avoided.

With regard to their connection in space: the three main types of salt occurrences are somewhat separated in their geographical relations; the flat salt beds are found in general in those areas where the downward movement came to an end in the early Jurassic and in which therefore the salt sank only a relatively small distance. These areas have experienced only slight post-Variscan deformation in connection with the relatively slight post-Variscan sedimentation.

The salt stocks are confined to the areas of stronger post-Variscan sinking and sedimentation, that is, especially the North German basin.

The salt anticlines are found in their characteristic form in the transition areas, therefore in the areas of medium sinking and sedimentation.

Certain zones of uplift can be traced from the peripheral areas far into the North German basin (35); *and with the advance into the latter, along one and the same line of uplift, the form of the anticline goes over more and more into the form of the salt stock.*

The time relations of the upthrust of the salt.—Of decisive importance for the significance of a salt upthrust are its time relations compared with the time relations of the other Saxon tectonics. In both cases time relations are ascertained through the help of angular unconformities, and it is to be said that in general the same series transgress over and around the salt formation which transgress discordantly elsewhere in the Saxon area. From those relations as well as from the massive sedimentation in the intervals between the periods of deformation of the salt formations, it follows that the salt beds participated in the above-described upward and downward movement of the Saxon fault-folding in the alternation of orogenic and epirogenic processes, and that they participated in a far stronger degree in the upward movement than the non-saline formations; the author illustrated this in a diagram published some time ago which showed only four periods of orogenic upward movement, but newer investigations now indicate that the number of the periods is much greater. To the transient character and periodicity of the folding

and of the upward movement of the salt masses, an exception is to be taken farther on, but if this exception is disregarded, it follows (27) *that the salt has been folded and has been moved upward in the same orogenic periods which are recognizable elsewhere as the periods of folding in the German terrane.*

The salt stock as the extreme form of an anticlinal core.—The position of the salt in the core of an anticline is very clear in the case of a salt anticline; the clarity, however, decreases with the transition to the salt stocks, and in individual extreme cases of salt stocks, the anticlinal position is perhaps no longer recognizable; but, as we have seen, salt stocks are tied together by transition of form and transition in space with salt anticlines, so that both must be explained in the same way. They fall, moreover, into the same periods of formation, if again we neglect the exception previously mentioned. The salt stocks, in last analysis, are the extreme form of anticlinal cores, in which the anticline is modified to unrecognizability; they are anticlinal cores that have advanced far ahead of the anticlinal wings and in the process have undergone an extensive change of form.

The rounded horizontal plan of many of the salt stocks does not contradict the conception of the salt as an anticlinal core; comparable forms, the so-called (structural) domes, are known also in Saxon structures of non-saline formations, and in fact they occur in many cases as the result of the summation of effects at the intersection of two axes of uplifts (see above). Thus it can be recognized that in many places in north Hannover the salt stocks lie at the intersection of the lines of uplift of Hercynian and Rhenish direction (29). In general, as in the Saxon tectonics, a substantial rôle is played by interference phenomena in determining the distribution and form of the salt bodies.

It appears therefore from (1) the recognizability of the occurrence of the salt as anticlinal cores or as derived from such through intermediate forms and through gradation in space, and (2) the contemporaneity of the upthrust of the salt with the periods of the Saxon folding, that it is not pertinent to call on other forces for the folding and uplift of the salt than those which folded and uplifted the non-saline beds of the German terrane.

The thesis is untenable and as yet has never been seriously advo-

cated that in salt anticlines the lateral formations have come into their present position through folding, while the salt has come into its present position in the anticlinal cores and has been deformed in general by other forces. If the salt anticlines have arisen under the same compression which, acting upon the earth crust, led to the Saxon folding, the same theory of origin should be valid also for the salt stocks, which are traceable from the salt anticlines in all degrees of transition. That the upward movement was far stronger and the inner deformation far more intensive than in the non-saline beds is explained by the extraordinary capacity of the material for deformation. By "inharmonious" folding the author understands the quantitatively and qualitatively unlike reaction of different rock masses of the same section to mountain-building forces. Thus schists fold much more intensively than the overlying quartzites and in many cases force themselves injectively into the gaps in the quartzite masses. The salt tectonics are nothing other than an extreme form of inharmonious folding (31). In Figure 5, in case (*a*) it is assumed that the beds from *a* to *l*, including beds *c* and *f*, have reacted harmoniously to the folding force, and thus a normal anticline arose, cut by a few faults. In contrast to this, in case (*b*), bed *c* is assumed to be highly mobile (salt) and bed *f* is assumed as more strongly mobile. When bed *c* is strongly compressed it advances far ahead of the overlying beds and bed *f* is disturbed in an increased degree next to the salt.

By the advocates of the theory of the autoplastic upthrust of the salt, it is assumed that the formations underlying the salt (middle Zechstein) are not involved in the upward movement and folding which affected the salt. Borings and exposures in shafts show the opposite; but that the more stable underlying formations are far less affected than the much-disturbed salt is quite in accordance with the picture of inharmonious folding.

THE SALT UPTHRUST AS AN INTERMEDIATE FORM BETWEEN NORMAL TECTONICS AND VULCANISM

Harbort, Rinne, and others have compared the upthrust of the salt with eruptive processes, since they assumed the cause of the upthrust to be the weight of the overlying sediment; but under the ex-

planation of the upthrust of the salt through lateral compression, the comparison with the upwelling of magmas still stands, so that in this sense the salt upthrust is "injective folding" (31). Salt tectonics therefore fill a gap in "normal tectonics," that is, between the tec-

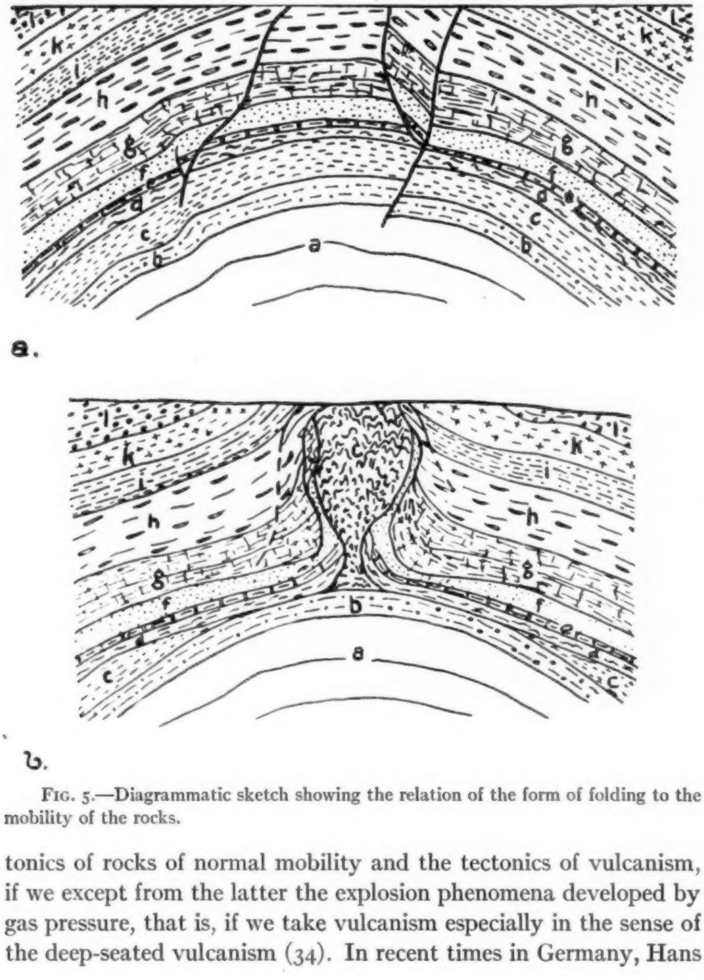

FIG. 5.—Diagrammatic sketch showing the relation of the form of folding to the mobility of the rocks.

tonics of rocks of normal mobility and the tectonics of vulcanism, if we except from the latter the explosion phenomena developed by gas pressure, that is, if we take vulcanism especially in the sense of the deep-seated vulcanism (34). In recent times in Germany, Hans

Cloos, starting from the micro-structure of the plutonic rocks, has advocated tectonic thrust as the cause of the rise of magma and its penetration into the beds of the earth's crust in the form of laccoliths; he has spoken of vulcanism as "the tectonics of highly mobile materials." Vulcanism, of course, is differentiated from the orogenesis of normal rocks in that it is not only tied up with the orogenic periods of the past, but in that it also occurs outside of those periods in times which in the structure of the normal rocks are characterized as exclusively epeirogenic. Not only the strong forces which are at work in orogenesis but also even the far weaker ones which call forth epeirogenesis, therefore, are capable of setting magma into movement on account of its high mobility. Salt in this regard is intermediate between the normal rock and the magma. If it was said previously that the folding and upward movement of the salt were confined to the well-known orogenic periods of Mesozoic and Cenozoic tectonics, the salt appears also exceptionally to have been highly disturbed once outside of these periods. Gripp (7) thinks he recognizes such an exception in one region in which the salt formations feeding the salt rock sank very deep and therefore were especially mobile. With that exception, the law of the time relations of orogenesis, that is, that orogenesis is confined to very definite periods of the earth's history which possess more or less world-wide significance, is valid for normal tectonics. Its validity for vulcanism, on the contrary, if we accept vulcanism as tectonic in Cloos' sense, is incomplete for although orogenic times are in general periods of increased vulcanism, yet vulcanism can take place outside those periods. For salt formations, also, the law of the time relation of orogenesis holds only with restrictions. As was expressed by Rinne, magma and salt, as mobile materials, as masses with very high capacity for deformation, react to tectonic forces far earlier than the rigid rocks (24).

The salt structure and even its extreme form, the salt stock, become understandable as structures of uncommonly mobile masses. The highly peculiar phenomena shown by the salt structures are sufficiently explained thereby and need not mislead us into postulating for their formation forces other than those which have given the non-saline beds their tectonic forms.

F. Rinne, the Leipzig scholar to whom we are indebted not only

for long years of investigation into the geology of German salt deposits, but also for his researches, holds the periodicity of the processes, of deformation, in the sense of the law of the time relation of orogenesis, as valid for the non-saline rock and considers it natural that plastic masses intercalated in those rocks should participate in temporary processes of folding and should hasten ahead of the adjacent formations. At the same time, according to him, the salt stocks can be brought into upward movement by the weight of the overlying beds. The fact of the covering of the salt by transgressive series, and in fact by the same series that appear transgressively quite generally in the Saxon terrane, finds an explanation in the fact that such series barred the way to the uprising of the salt in shattered territory, as the result of the weight of the overlying beds. But as the deformation in the adjacent formations, which are cut off equally by the transgressive series, is older than the transgression, the much more pertinent assumption is that the salt had experienced upward movement before the transgression, together with the adjacent formations; that is, that the transgression series was laid down on the salt, and not conversely that the salt was gradually pushed up to the transgressive series. Rinne asserts especially that mountain-building, salt upthrust, and magma intrusion lead back to a single fundamental motive force, gravity. But does not the unity of this motive force remain protected if salt upthrust and intrusion of magma are brought into connection with the phenomena of folding? for this also in the last analysis finds its cause in gravity. The salt upthrust in this sense, is not an immediate but an indirect effect of gravity, for the tectonic forces active in the earth's crust arise first of all from gravity, and these forces cause the salt to move upward.

In Arrhenius' hypothesis, the upthrust of the salt as a result of its lesser specific gravity depends on the direct effect of the gravitative field. But in this case the comparison with magmatic upthrust fails; the uprising masses of magma in many cases are heavier than those through which they are being forced. If we wish to speak of magma upthrust as tectonic here, it is surely only the increased mobility which is the cause of the increased movement. There is a contradiction in the fact that on one side the upthrust of the salt is

compared with the upthrust of magma, and on the other side the upthrust is to be explained through the lesser specific gravity of the salt.

CONCLUSION

If the formation of the German salt anticlines is attributed to the same compressive thrust which has affected the beds above and below the salt formation, then, if one does not wish to separate things which quite evidently and naturally belong together, orogenic thrust must be recognized as the cause of the upthrust and of the inner change of form of the salt stocks as well. That the salt stocks project as folded formations into the middle of block-faulted masses of adjacent beds and of the cover, that the salt has therefore been more intensively deformed than the adjacent beds, and that, coincidently with its heightened inner deformation, it has advanced in the general deformation far ahead of the non-saline adjacent formations, is explained sufficiently by its higher mobility. This is merely a special case of general experience that the form to which orogenesis leads is principally a function of the mobility of the material in question (33). In this sense, the salt stocks illustrate the extreme case of inharmonious folding.

Thus the author conceives the upthrust of the salt less as the ejection of an especially *light* material than as that of an especially *mobile* material. In this sense, there is agreement with the upthrust of magma, which in so many cases is heavier than the beds which it penetrates.

Against the explanation of the upthrust of the salt isostatically through the weight of the overlying cover, there is the connection of the movement of the salt with the periods of Saxon orogenesis. The fact that quite exceptionally salt bodies appear once to have been moved upward outside of these periods may be explained by the fact that the salt, as a rock of very highly increased capacity for deformation, reacts to lesser tectonic forces that could effect no deformation in the normal rocks. Thus the movement of the salt fills a gap between the tectonics of deformation of normal periods, and the upward movement of magma which occurs so often outside such periods.

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DISCUSSION

D. C. BARTON: Stille's views have been severely questioned recently by Franz Schuh[1] in the three papers in *Kali*. The following is a digest of a rather detailed review by Brinkmeier of the papers.[2]

Schuh discusses the two fundamental theories of mountain-building, contraction, and isostasy, and, accepting the latter, is enabled to regard compression and tension as co-ordinate, while advocates of the contraction theory have to regard tension and uplift as subordinate to compression. In a critical discussion

[1] "Beitrag zur Tektonik unserer Salzstöcke," *Kali*, Heft 1; "Die saxonische Gebirgsbildung," I, II, *Kali*, Heft 8; "Salztektonik," *Kali*, Heft 17, 18.

[2] *Zeitschrift für angewandte Geophysik*, I (1923), Heft 3, pp. 86–89.

of Stille's views of the later Mesozoic (Saxon) mountain-building in Germany, he attempts to show that at the beginning of the folding in the Cimmerian period," a tectonic frame (*Rahmen*) in Stille's sense was not present, and, rejecting Stille's "injective folding," advocates the view that the Cimmerian and early Senonian folding belongs in two completely different dynamic periods; i.e., that the first indicates a period of tangential tension, and that the second indicates a period of tangential compression in a southwest-northeast direction; that is, in contrast to Stille's belief in "fault-folding" repeated in every tectonic period, he regards the separation of the faulting from the folding as necessary and possible.

The essence of the author's views, in regard to salt dome tectonics, is that the salt stocks correspond genetically to the graben of normal tectonics; that the areas of depression (*Senkungsfeld*) on either side of the salt stock correspond to horsts which remained standing, and between which the graben sank, and that salt stocks, as well as grabens, go back in their origin to tension faults. On the ground of these assertions, for which no real evidence is brought forward, the views of Stille in regard to the special connection of horsts, normal anticlines, and anticlinal swells (*Breitsättel*) on the one side, and shallow synclines (*Breitmulde*), synclines, and grabens on the other, are regarded as erroneous. Stille's explanation of the formation of these various structures from the character of the deep-lying Variscan basement is rejected as resting on mechanically impossible conceptions, while the effect of the massive cover is recognized only in Harbort's and Seidl's sense. The conception of the Cimmerian period as a period of tangential tension is combined in the explanation of the upward movement of the salt forces.

After contrasting the opposing views of Lachmann, Stille, and Harbort, Schuh accepts Harbort's conceptions, as expressed by Seidl in his "Notes on the Theory of Genesis of the Permian Salt Deposits in Middle Germany": i.e., that the upward flowage of the salt masses is brought about originally by tectonic causes, and takes place along zones of dislocation, and that the concomitant squeezing out of the salt under the flat-lying blocks on either side results in a sinking of the center of each block and a tilting up of its edges. On the assumptions (1) that the salt formation is overlain by a massive cover several kilometers thick; (2) that after a period of faulting following tangential tension there follows a longer period of relative tectonic quiet, and then a period of tangential compression in a northeasterly direction; and (3) that the cover yields easily, but does not fracture, he attempts to show experimentally that such special features arise as gentle archings between the fracture zones, movement of the plastic material (salt) to the fracture zones, rupturing of the less plastic beds, piercing and upward bending of the edges of the cover.

The type of the form of the salt stock, according to Schuh, depends on the varying types of combination of fracture systems, i.e., he predicates "intersection of fractures" in contrast to Stille's "intersection of axes" and "axial nodes."

The tangential compression in the later periods, he believes, causes a decrease in the width of the salt stock and forces it up, and causes the formation of an anticline in the prolongation of the salt stock, if the fracture through which the salt has risen is perpendicular to the direction of thrust. If, however, the fracture runs parallel to the direction of thrust, this late tangential compression causes the broadening and cross-folding of the salt stock and the formation of a broad arch.

On the basis of the published data, he discusses the tectonics of many of the German salt domes, and, according to the reviewer, rather tries to bend the published descriptions of the structure to his previously conceived theories in a way that would probably not be acceptable to most of the respective authors. Although known in a few cases, the tectonics of the basement underlying the salt deposit remains unconsidered by Schuh.

Brinkmeier's verdict regarding the paper is that Schuh fails to prove his point, and instead of presenting definite evidence, reiterates mere assertions. He believes, however, that even if it is not possible to agree with the author's arguments, yet that they may present suggestive points of view for future work.

APPARATUS FOR DETERMINING THE ABSORPTION AND THE PERMEABILITY OF OIL AND GAS SANDS FOR CERTAIN LIQUIDS AND GASES UNDER PRESSURE[1]

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ABSTRACT

By means of specially designed apparatus which is described, oil- and gas-sand samples may be subjected to accurately measurable pressures, under which reliable quantitative determinations of absorption and permeability of the sands for certain fluids such as oil, fresh and salt water, and gases can be made. Application of absorption and permeability investigations on typical oil and gas sands to method of recovery is important.

INTRODUCTION

The pressure apparatus described in this paper was built to determine the degree and rates of absorption of oil sands of different textures for water and oils of different viscosities under varying pressures and temperatures. Experiments are to be made on accumulation and migration of oil under pressure. The pressure apparatus is to be used for experiments on recovery of oil sands of various textures, or the amount of oil that a sand saturated with oil and gas will yield when the pressure is released to the atmosphere. It is hoped that these experiments will not only give a better understanding of the forces that operate in accumulation and migration of oil, but will be of use in determining the percentage of saturation, estimates of recovery, and the adaptability of oil sands for such methods of recovery as water flooding, compressed air, and vacuum.

The pressure apparatus is shown as a whole in Figure 1, a diagram of the pressure chamber in Figure 2, and the pressure piston and cylinder in Figure 3.

A twofold purpose was kept in mind in the design of the pressure chamber: the pressure chamber must not only be large and easily accessible, but must be made to withstand a hydraulic pressure of

[1] Published by permission of the director, U. S. Geological Survey.

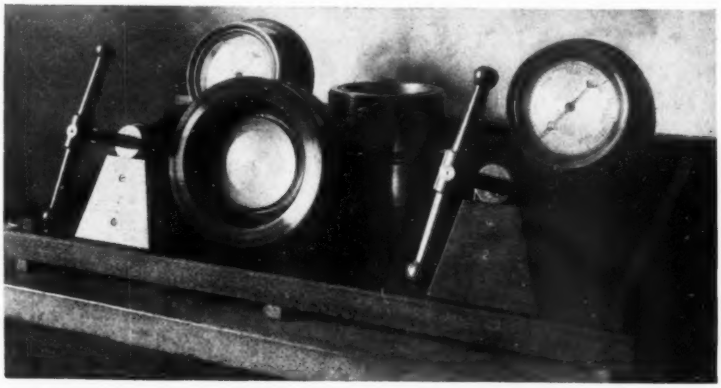

FIG. 1.—Pressure apparatus with cap removed

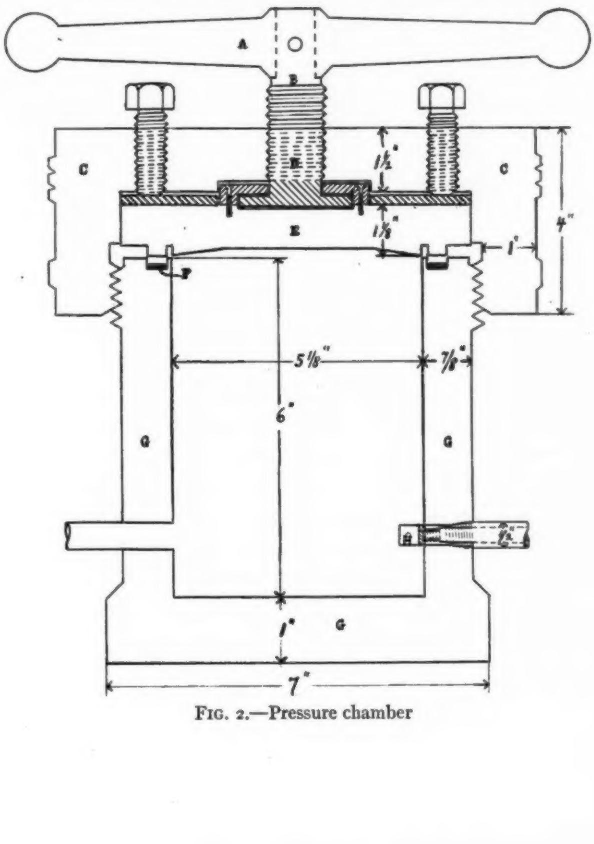

FIG. 2.—Pressure chamber

3,000 pounds to the square inch with practically no leakage. To satisfy these requirements, the pressure chamber consisted of four mains parts, an outer cap *C*, inner cap *E*, pressure screw *D*, and handle *A*, and the main body of the pressure chamber *G*. All the parts were made of brass except the pressure screw, which was made of steel. To close the pressure chamber, the inner cap is screwed up by the screw *D* into the outer cap as far as it will go. The outer cap is screwed down over the pressure chamber, then the inner cap is forced down on the top of the pressure chamber by the pressure screw *D*. When the flange of the inner cap rests on the leather gasket *F*, the pressure screw turns in the socket at the top of the cap *E* without turning the cap itself. This method of forcing the inner cap down on top of the pressure chamber without turning the inner cap prevents injury to the gasket which is placed in the depression at the top of the pressure chamber. For lower pressures, sufficient force can be applied to the pressure screw by the handle *A*, but for higher pressures (from 1,000 to 3,000 pounds to the square inch), the six bolts which extend through the outer cap *C* are tightened.

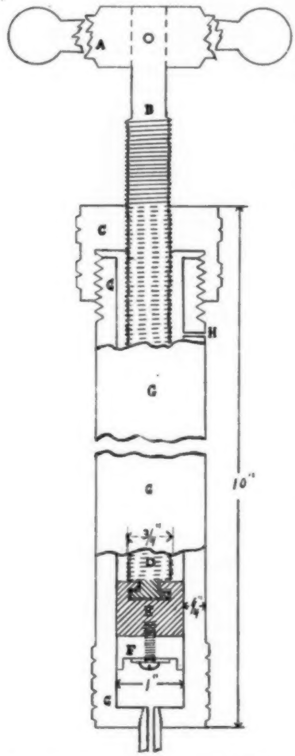

FIG. 3.—Pressure piston and cylinder

Pressure is applied to the confined liquid in the pressure chamber by the screw *D* and piston *E* in Figure 3. A tight-fitting piston is formed by a leather cup-shaped gasket *F* fastened on the end of the piston. This cup-shaped gasket is in common use at the U.S. Bureau of Standards.

The pressure pumps are made in duplicate; one is used for oil and the other for fresh or salt water. The duplication of the pressure

pumps saves labor of cleaning the pump when the liquid is changed. A needle valve[1] is inserted in the tube leading from the pressure pump, and is used to close the opening from the pressure pump and hold the liquid under pressure in the pressure chamber. The pressures are read by hydraulic pressure gauges calibrated by the U.S. Bureau of Standards.

COMPARISON OF WATER ABSORPTION WITH PORE SPACE

Comparisons were made of the percentage of water absorption at various pressures with the percentage of pore space by volume of three building-stones. The samples were cubes and consisted of a red sandstone (1), a brown sandstone (2), and an Indiana limestone (3), furnished by Mr. D. W. Kessler, of the U. S. Bureau of Standards.

The samples were first dried in an electric oven at 110° C. for 52 hours and weighed after they were cooled in desiccators. The samples were again placed in the electric oven and dried at 142° C. for 22 hours and weighed after they had cooled in the desiccators. The greatest change in weight for the two dryings at the above temperatures was a decrease in weight of 0.3 grams for the red-sandstone sample. The samples were then placed in shallow trays containing about $\frac{1}{2}$-inch of distilled water. Distilled water was added at intervals of 2 to 3 hours until the samples were completely covered. After the samples had been immersed in the water for 93 hours, they were taken out, one at a time, their surface water being removed with a towel, and weighed. A check weighing was made on each sample.

The red and brown sandstones were then placed immediately into the pressure chamber of the pressure apparatus containing distilled water and were subjected to a hydraulic pressure of about 250 pounds for 20 minutes. The samples were taken out, one at a time, their surface water removed, and weighed. They were again placed in the pressure chamber and subjected to a hydraulic pressure of 1,000 pounds. The next morning the pressure had dropped to 300 pounds. The pressure was then maintained at 300–600 pounds for

[1] This type of needle valve is described by J. W. Cook, "The Production of Liquid Air on a Laboratory Scale," *U. S. Bureau of Standards, Scientific Paper No. 419*, pp. 285–86, 1921.

6 days, when the samples were removed, their surfaces were dried, and the samples weighed.

The results of this experiment are given in Table I. The temperature of the water was taken at the time of each weighing, and the volume of the water was computed from its density. The difference in the first two determinations of percentage pore space by volume and the third determination of sample No. 2 is due to two different texture types of this sample. The difference between the percentage

TABLE I

COMPARISON OF ABSORPTION OF BUILDING-STONES FOR WATER AT VARIOUS PRESSURES WITH THE TOTAL PERCENTAGE OF PORE SPACE

Sample No.	Dry Weight (Gms.)	Water Absorbed at Atmospheric Pressure		Water Absorbed under 250 lbs. Pressure for 20 Min.		Water Absorbed at 1000 lbs. Pressure		Total Pore Space, Percentage by Volume
		Weight (gms.)	Percentage by Volume	Weight (gms.)	Percentage by Volume	Weight (gms.)	Percentage by Volume	
1......	450.25	26.29	12.9	28.69	14.0	36.55	17.9	17.3 17.9 18.5 Av. 17.9
2......	518.02	16.29	7.5	18.47	8.5	25.68	11.9	10.7 10.6 13.4 Av. 11.6
3......	441.49	29.20	14.6	....	....	....	....	19.4 18.8 18.9 Av. 19.0

of water absorbed by volume at 1,000 pounds pressure and the average percentage of pore space by volume of samples Nos. 1 and 2 are well within the limits of experimental errors. The close agreement of the average percentage of pore space by volume with the percentage of water absorbed under 1,000 pounds pressure of samples Nos. 1 and 2 not only gives a check on the methods, but indicates that the pores of granular oil- and gas-producing sands are completely filled with some flowing substance or substances as oil, gas, and water, especially when these sands are under 1,000 pounds pressure. This experi-

ment tends to confirm the axiomatic statement by Carl H. Beal and J. O. Lewis[1] that no vacuum exists in an oil sand, but each void is filled with water, gas, or oil.

ABSORPTION TESTS ON BUILDING STONES

The results of the above experiments on pore space and absorption of water by rocks under pressure confirm the results of the determinations of pore space by Julius Hirschwald,[2] who shows that pore-space determinations based on water absorption very seldom

TABLE II

PERCENTAGE PROPORTION OF WATER ABSORPTION TO TOTAL PORE SPACE*

No. of Sample	By Method of Quick Immersion	By Method of Gradual Immersion	By Method of Gradual Immersion in Boiling Water under a Vacuum (2 cm. or Less Pressure of Mercury)	By Method of pressure 50–150 Atmospheres
1	53.0	61.3	85.5	100.0
17	45.9	52.2	61.1	100.0
11	71.3	81.2	81.5	100.0
2	60.9	63.0	99.4	100.0
4	72.6	77.2	81.0	100.0
18	53.3	54.6	99.5	100.0
16	47.6	49.7	96.1	100.0

* The total pore space in these seven cases is the same as the pore space determined by the method of, applying a pressure of 50–150 atmospheres to the sample under water immediately after the method of gradual immersion in water under a vacuum has been completed.

give the correct value for building-stones unless the samples are placed in water under pressure. In this case a pressure of 50 atmospheres or more was used to saturate the samples.

MOUNTING FOR THE DETERMINATION OF PERMEABILITY OF OIL SANDS

Figure 4 shows the mounting made of brass, cross-section of the mounting, and outer and inner sleeve of the mounting. On the cross-section of the mounting, 1 indicates the oil-sand specimen which rests on the sharp-edged top of the inner sleeve 5 and against the

[1] "Some Principals Governing the Production of Oil Wells," *U. S. Bureau of Mines Bull. 194*, p. 9, 1921.

[2] *Die Prüfung der natürlichen Bausteine auf ihre Wetterbeständigkeit*. Berlin: W. Ernst und Sohn, 1908.

outer sleeve 3. The top of the outer sleeve is beveled so that samples of various sizes can be used, and a large specimen can be reduced in size so that the distance between the outer sleeve and the top of the inner sleeve can be decreased by reducing the size of the oil-sand specimen.

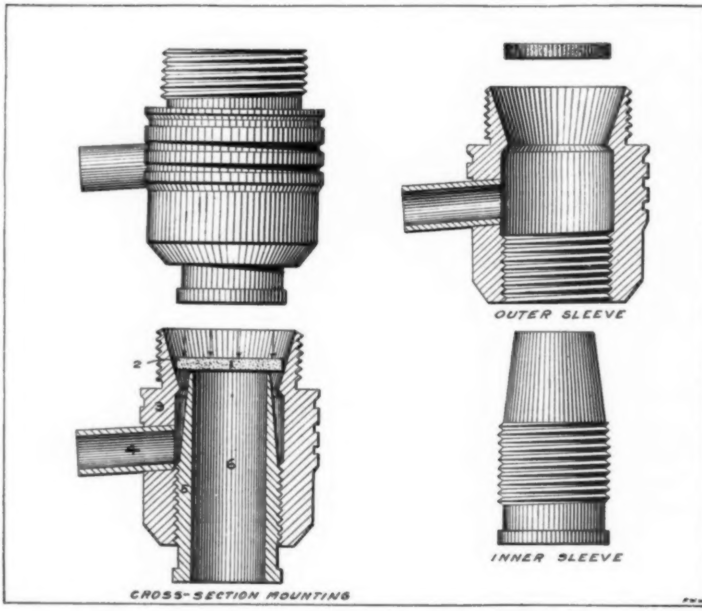

FIG. 4.—Mounting for determination of permeability of oil sands

The sloping sides of the outer sleeve at 2 also permit space between the sample and the sleeve to be filled in by a cement such as De Khotinsky or sodium silicate. If a very friable sample is used, a wire gauze, which has been calibrated for permeability, is placed on top of the inner sleeve to keep the sample from breaking down when pressure is applied. A series of shoulders on the sloping sides of the outer sleeve will assist in holding indurated samples of different sizes where high pressures are used.

The mounting is designed to furnish an area and thickness of the

oil sand which can be measured accurately. The inner face of that part of the oil-sand specimen that is actually used for determination of permeability is equal in area to the opening in the inner sleeve 6. The design of the apparatus eliminates any error due to leakage along the sides of the specimen, as any liquid which leaks by the sides passes out through the exit 4. Any diagonal flows, eddy currents, or error due to cement can be studied, corrected for, or eliminated by changing the area of that part of the specimen between the inner and outer sleeves, or by using inner sleeves of different internal diameters and making a new determination on the same specimen.

MOUNTING SAMPLE FOR PERMEABILITY

In operation, the oil- or gas-sand specimen, which is prepared in the form of a disk, is placed in the beveled opening at the top of the outer sleeve. The inner sleeve is then screwed up into the outer sleeve until its top edge comes into contact with the specimen. The space between the sample and the outer sleeve at 2 is filled with cement, and the mounting containing the specimen is then screwed into the outlet of the pressure apparatus, which is inclosed in a thermostat. The liquid or gas pressure is applied in the direction of the arrows shown in the cross-section of the mounting.

The quantity of liquid which flows through the sample into the inner sleeve for any given time, pressure, and temperature can be measured accurately either by removing the inner sleeve with its liquid and weighing it, or by letting the liquid flow into an inclosed receptacle underneath the inner sleeve and weighing. The quantity of gas which flows through the specimen for any given time, pressure, and temperature can be measured by a gas meter when gas is being used for determinations of permeability. The gas in the openings 4 and 6, which are shown in the cross-section of the mounting, should be kept at about the same pressures, so that the error due to transfer of gas from one opening to the other will be negligible.

The apparatus for determining the permeability of oil and gas sands for liquids and gas is shown in Figure 5 without the mounting.

This design of mounting oil-sand samples gives an accurate and convenient method for studying permeability of oil sands. The mounting will be used to study the various physical properties of

oil sands and methods of recovery of oil, as has been outlined by the writer.[1]

The writer is indebted to Lyman J. Briggs, of the U. S. Bureau

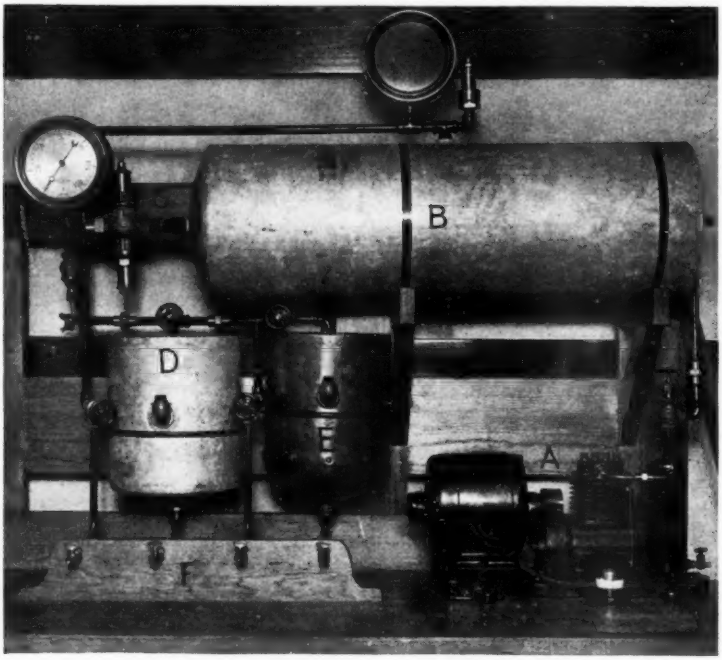

FIG. 5.—Apparatus without mounting for the determination of permeability: *A*, air pressure pump; *B*, large reserve pressure tank and gauge; *C*, constant pressure-reducing valve and gauge; *D*, oil pressure tank; *E*, salt-water or fresh-water pressure tank; *F*, outlets for attaching mounting containing sample for test.

of Standards for suggestions on the design of this mounting. R. L. Atkinson, the Geological Survey mechanician, built the apparatuses and gave helpful suggestions on their design.

[1] "Investigations on Permeability and Absorption of 'Sands' for Oil, Water, and Gas, with Reference to Their Normal and Possible Yield," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 6 (1922), p. 143.

THE DETERMINATION OF FORMATION THICKNESSES BY THE METHOD OF GRAPHICAL INTEGRATION

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ABSTRACT

The article describes a method for estimating with considerable accuracy the thickness of strata exposed in any section at the surface. The dip of the beds may vary from place to place in the section in any manner whatsoever so long as the beds are not overturned, and the folding may be of either the similar or parallel types. A curve is plotted based on the various dips, and the area inclosed by this curve or any portion of it is used for the purpose of calculating the formation thickness. The method is especially adapted for calculating thicknesses in sections having low angles of dip.

The method described below for determining the thickness of strata is based on the principle of definite integrals in the calculus, but the application of the method requires on the part of the operator no greater mathematical accomplishments than a knowledge of the use of a table of natural trigonometric functions, as sines and tangents, and the ability to determine the area of an irregular figure by means of a planimeter, counting the squares, use of Simpson's Rule, or similar devices.

The method has the advantage of estimating formation thicknesses with considerable accuracy, perhaps with greater accuracy than is obtainable with the usual methods now in vogue for this purpose. The writer does not know whether the applications given are new, but as they are based on fundamental mathematical principles, it would seem strange that they are not in more frequent use where accuracy is desired.

As a first requisite, the geologist must determine a series of dips in an approximately straight line, or so that they are reducible to such a line, at right angles to the strike of the beds to be measured. The dips, which are measured from the horizontal plane, may have any degree or variation, so long as the beds are not overturned. It is necessary to know the horizontal distance of each dip from the starting-point, and also the elevation above a chosen datum plane.

The application of graphical integration is shown for two types of folding, similar and parallel. The question of determining whether the strata are deformed into parallel or similar folds must be left to the geologist. With bedded deposits consisting of more or less competent layers, the parallel type should be used, and this type is, in fact, the one on which the determination of formation thicknesses is commonly based in practice.[1] If a deposit to be measured is soft and plastic for the most part, the similar type is apt to be the one under which the beds are folded.

CASE I. STRATA IN SIMILAR FOLDS, WITH EXPOSURES AT ANY ELEVATION

In similar folds (of the rectangular type), the thickness between two horizons is most conveniently represented by the vertical distance between the horizons, rather than the distance taken along a line drawn at right angles to the dip, as the first represents a constant value, while the latter is a variable, in cases where there is variation in dip from point to point.

Figure 1B represents a section some 700 feet long where the beds are presumed to be in similar folds. This, for example, may represent a belt of soft shales included in a series of bedded formations, not shown, the object being to obtain the structure and thicknesses of the shale belt in this vicinity. Figure 1A shows a small portion of this belt for the purpose of explaining the method. Symbols a_1, a_2, a_3 show the angle of dip at three consecutive localities, and Y_1, Y_2, Y_3, the respective thicknesses if folded by the similar law. The total thickness exposed is the sum of these three values, or

$$Y_1+Y_2+Y_3=x_1 \tan a_1+x_2 \tan a_2+x_3 \tan a_3 \, .$$

If now the portion shown in Figure 1A were to be lengthened considerably, so as to consist of a great number of these small triangles, each with a different dip, the total thickness exposed between the beginning of the line and some point x on it would be, in the notation of calculus, the definite integral

$$Y=\int_0^x \tan a \, dx \, .$$

[1] E. L. Ickes, "Features of Similar, Parallel and Neutral Surface Types of Folding," *Econ. Geol.*, Vol. 18 (September, 1923), pp. 575–91.

This integral represents an area, and if the area is determinable, the value of Y, the thickness, is found. As will be shown below, the

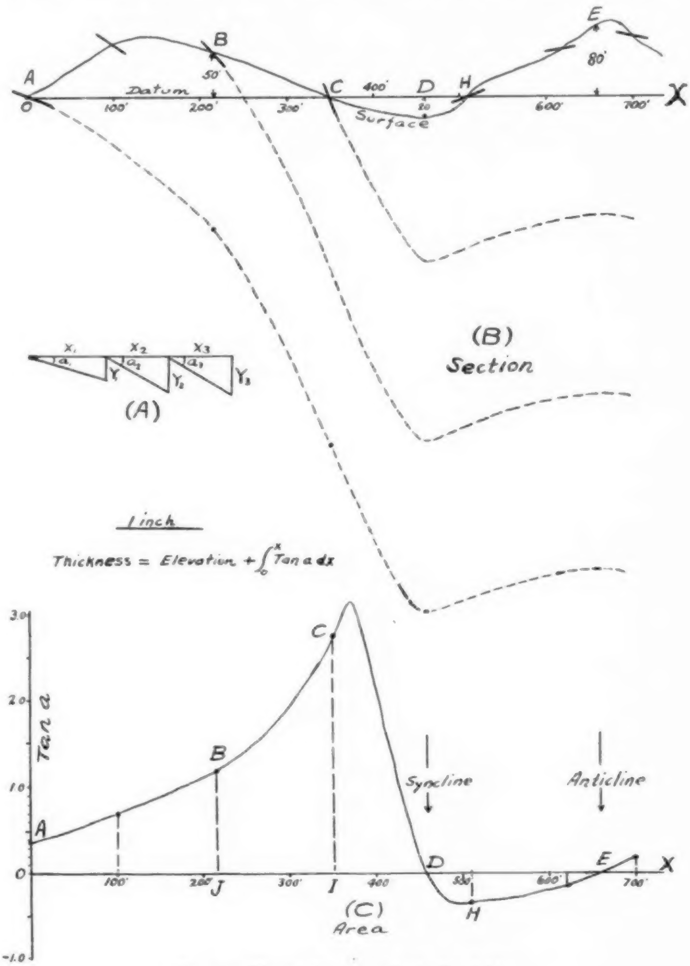

FIG. 1.—Illustrating Case I, similar folds

graphical evaluation of this integral is not a matter of much difficulty.

In similar folds of the rectangular type, the elevations of the dip localities above or below the datum plane selected, such as sea-level, do not complicate the calculations as in the case of parallel folds. That is, on account of the fact that the thicknesses are measured vertically in similar folds, in the same direction as the elevations, the correction for elevation is a simple matter with similar types.

In the section represented by Figure 1B, the dips found in the exposures detected are at A, B, C, etc., and are represented by the short, heavy lines. The line OX represents the trace of the datum plane, here selected so as to pass through the first dip at station A. If only the thickness of beds exposed is desired, it is not necessary to draw the section. From his notes or maps the geologist begins by making a table like Table I, which are the data shown on the profile.

TABLE I

Distance, x	Dip, a	Tan a
0	$+20°$	$+ .364$
100	35	.700
215	50	1.192
350	70	2.748
510	-20	$- .364$
620	-10	$- .176$
700	$+10°$	$+ .176$

Dips to the right are considered positive, those to the left negative, but if more convenient these can be reversed, the only requirement being that right- and left-hand dips are distinguished in sign.

We next come to the most important point in the method, that of graphically integrating the integral by finding an area, and so determining the thickness. Figure 1C shows the next step. The horizontal distances in Table I are set off on the datum line OX. The values of tan a are set off on the vertical axis, the positive values of tan a being above, and the negative ones below, the datum line. The various points so plotted are then connected by a smooth curve, the geologist using his judgment as to how to draw this. The greater the number of points determined, the greater will be the accuracy of the results. It will be noted that the probable dip at any unexposed point can be estimated by scaling off the tangent value from

the curve for that point, and from the table of functions finding the corresponding angle.

The areas which represent the thicknesses are determined from Figure 1C. A planimeter is the most satisfactory means of finding these areas. To illustrate the method, we may proceed as follows:

The thickness of strata exposed between *O* and *B* in the section, Figure 1B, is the elevation of exposure *B* plus the area *ABJO* in the lower figure, 1C. It is found that *ABJO* has an area of 1.55 square inches. Now 1 square inch in Figure 1C is made up of 1 inch horizontal by 1 inch vertical, and since on the horizontal scale 1 inch is equivalent to 100 feet and on the vertical scale to 1.0 (no dimensions), we find that 1 square inch is equivalent to $100 \times 1 = 100$ feet, 1 square inch thus having the dimensions of length. Hence area $ABJO = 1.55$ square inches $= 1.55 \times 100$ feet $= 155$ feet, and the total thickness of beds exposed between *A* and *B* in the section is the elevation of *B*, or 50 feet, plus 155 feet, giving a total exposed thickness of 205 feet.

The thickness of strata exposed between *O* and *C* in Figure 1B is equivalent to the area *ABCIO* in Figure 1C. In this instance no correction is necessary for elevation, since the exposure is on the datum plane. The area mentioned contains 4.02 square inches, and since 1 square inch represents 100 feet, the total thickness exposed from *A* to *C* is 402 feet.

Point *D* in the profile represents the synclinal axis, and the position of this with reference to the starting-point *A* is found from Figure 1C, where the curve crosses the line *OX*. Similarly, the probable position of the anticlinal axis is at *E*, where the curve again crosses the line. The thickness exposed between *A* and *D*, the syncline, is the elevation of *D*, or -20 feet, plus area *ACDO* in Figure 1C. This area contains 5.97 square inches, representing a thickness of 597 feet, so that the total thickness exposed to the synclinal axis at *D* is $-20+597$, or 577 feet.

Again, the thickness exposed between the starting-point *A* and *E*, the anticlinal axis, is equivalent to the elevation of *E*, or 80 feet, plus area *ACDO* minus area *DHE*, the areas being shown in Figure 1C. These areas are respectively 5.97 square inches and -0.48 square inch, and their algebraic sum is 5.49 square inches, or 549 feet. Hence

the total thickness exposed between A and the anticlinal axis at E in the profile is $80+549$, or 629 feet.

The above examples will suffice to show the mode of operation. In drawing the resulting section, the thicknesses determined are projected vertically, and not at right angles to the dip, to get the underground positions of the various horizons.

DETERMINATION OF THICKNESS WHEN THE STRATA ARE IN PARALLEL FOLDS

This will be the method used for most cases in practice. In parallel folds, the thickness is measured along a line at right angles to the dip. Thus, the total thickness exposed along the small portion of section represented by Figure 2A is

$$T_1+T_2+T_3=x_1 \sin a_1+x_2 \sin a_2+x_3 \sin a_3 ,$$

and if we have a long section made up of numerous small triangles such as shown, the total thickness exposed between the starting-point and any point x on the section is represented by the definite integral

$$T=\int_0^x \sin a \, dx .$$

Owing to mathematical complications, it is not easy to find the thickness with parallel folds unless the exposures all have the same elevation. In cases of moderate deformation, however, it is possible to determine the thickness by the present method when the exposures have different elevations, as shown in cases III and IV.

CASE II. STRATA IN PARALLEL FOLDS WITH EXPOSURES AT THE SAME ELEVATION

The short, thick lines in Figure 2B represent dips taken at the various exposures and shown in their relative positions. The procedure for determining thicknesses is much the same as in the case of similar folds, explained in Case I. The data are tabulated as in Table II.

The values in the table are next plotted as in Figure 2C, the horizontal distances being set off on the axis OX, and the sines of the

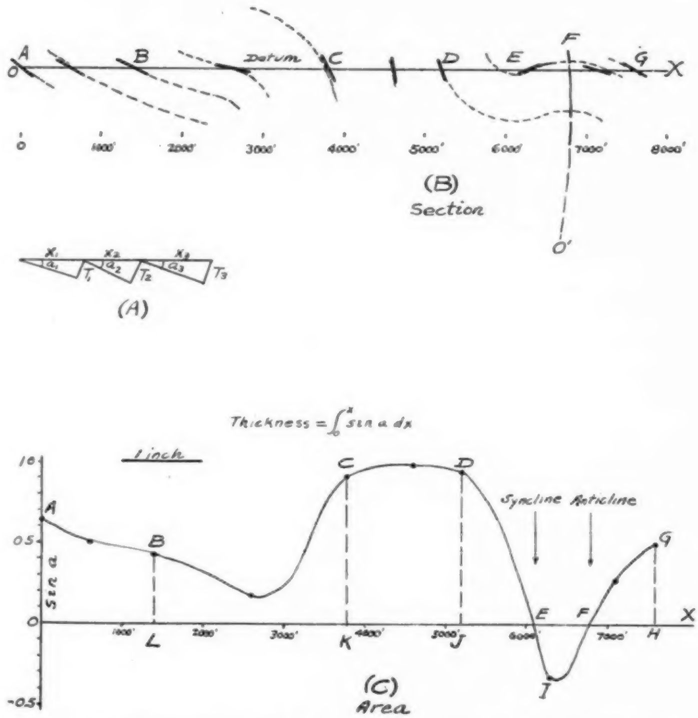

FIG. 2.—Illustrating Case II, parallel folds, with exposures at the same elevation

TABLE II

Station	Distance, x	Dip, a	Sin a
	Feet		
A..................	0	$+40°$	$+.643$
	600	30	.500
B..................	1,400	25	.423
	2,600	10	.174
C..................	3,800	65	.906
	4,600	80	.985
D..................	5,200	70	.940
	6,300	-20	$-.342$
	7,100	$+15$	$+.259$
G..................	7,600	$30°$	.500

angle of dip on the vertical axis. As in Case I, the points so determined are connected by a smooth curve, and from the areas inclosed by this curve the various thicknesses required are found. As in the previous case, it is necessary to distinguish between right- and left-hand dips by using plus and minus signs respectively.

The dips show that a syncline and anticline occur in the section, and the probable position of the axes of these folds can be found from the points where the curve of Figure 2C crosses the horizontal axis, the syncline being at point *E*, a distance of 6,100 feet from the starting-point, and the anticline at point *F*, a distance of 6,800 feet.

The total thickness of strata exposed by parallel folding between *O* and the syncline *E* is represented by the area *ABCDEO* in Figure 2C. This area contains 7.10 square inches. With the scales selected, 1 square inch consists of 1 inch = 1,000 feet horizontally, and 1 inch = 0.50 vertically, so that 1 square inch in the diagram is equivalent to $1{,}000 \times 0.50 = 500$ feet. Hence an area of 7.10 square inches represents 3,550 feet as the thickness exposed between the given points.

The thickness exposed between *O* and the anticline *F* is equivalent to the area *ABCDEO* minus area *EIF*, or 7.10 square inches $-$ 0.33 square inch = 6.77 square inches. Since 1 square inch is the same as 500 feet, the thickness exposed is 6.77×500, or 3,385 feet.

Similarly, the thickness exposed between exposures *B* and *C* is equivalent to the area *BCKL* in Figure 2C, or 1.80 square inches. Therefore the thickness exposed in this interval is 1.80×500, or 900 feet.

Again, the thickness of beds exposed between *O* and exposure *G* on the flank of the anticline is represented by areas (in Figure 2C) *ABCDEO* minus *EIF* plus *FGH*, or $7.10 - 0.33 + 0.45 = 7.22$ square inches, the equivalent of $7.22 \times 500 = 3{,}610$ feet of thickness.

It should be noted that the thicknesses determined by this method are those *exposed* at the surface along the horizontal line *OX*. In drawing the resulting geological section, Figure 2B, these thicknesses are laid off along lines drawn at right angles to the dips, in the case of parallel folds. In the example selected, however, the folding is of such degree that the perpendicular lines, while starting off as straight lines, soon become curved, and so far as the writer is aware, there is no published method explaining how these lines should be

drawn and the horizon positions plotted. With the information available in the section given, the plotting of the underground structure is a matter of inference. For example, let us suppose the outcrop at O or A in the section is an oil sand, and we know from the above results that the thickness of strata exposed between the oil sand and the crest of the anticline at F is 3,385 feet. In the present instance, however, we are not able to draw a straight line vertically downward from point F and lay off 3,385 feet along it to find the probable position of the sand. The type of folding suggests that the axial "plane" of the anticline is some inclined curved surface, whose trace is represented by a curved line such as FO' in Figure 2B. The length to be measured along this trace to find the oil sand would be some function of the value 3,385 feet.

CASE III. STRATA IN PARALLEL FOLDS OF MODERATE DEGREE, WITH EXPOSURES AT ANY ELEVATION

The method is the same as in Case II, but in the present instance correction is made for difference of elevation of the exposures. Figure 3A shows the exposures plotted with reference to both their horizontal position and elevation above or below the datum plane OX. In order for the method to be applicable, the dips must be of such nature that the line drawn perpendicularly from a given dip must intersect the OX axis or datum line at a greater distance from the origin or starting-point than a similar normal line drawn from the next preceding dip.

Referring to Figure 3A, let z be the horizontal distance to any exposure from the starting-point O, and E the elevation of the exposure with reference to the datum line OX. From the exposure dip draw a line perpendicular to the direction of dip so as to intersect the datum line, and let x represent the point of this intersection. Then in general

$$x=z-E \tan a ,$$

where a is the angle of dip, positive if to the right, negative if to the left.

Now, at point x the dip is the same as the exposure dip, on account of the constancy of dip along orthogonal lines in parallel folding, so that by plotting the various points x with their respective

dips we get a curve which can be graphically integrated, as in Case II, to determine the thicknesses from the starting-point to any

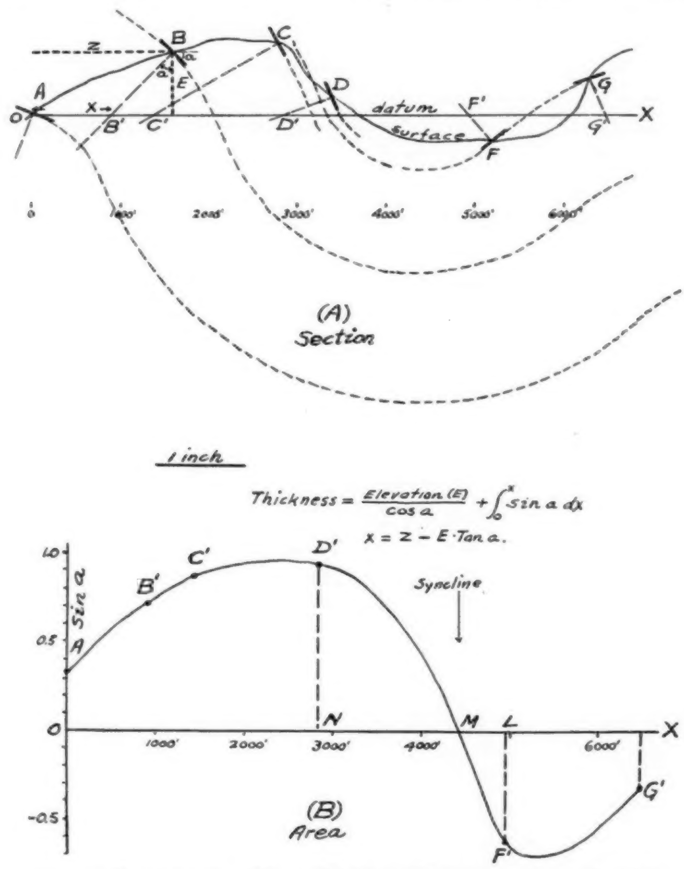

FIG. 3.—Illustrating Case III, parallel folds, with exposures at any elevation

point x on the datum line. As in the preceding cases, this is represented by a definite integral which we shall call

$$T_1 = \int_0^x \sin a \, dx \, .$$

To this thickness must be added or subtracted the correction for elevation of the exposure, namely $E/\cos a$. Elevations above the datum line are positive, those below are negative.

The information is tabulated for convenience as in Table III.

The curve shown in Figure 3B is formed by plotting the values of calculated distances x on the horizontal axis, and values of sin a on the vertical axis.

To show the manner of operation, a few examples are given. Thus, to find the thickness exposed between O and exposure D in Figure 3A. Here D' represents the perpendicular projection of D on the datum line, and in Figure 3B the area of $AD'NO$ is 4.40 square inches. Now, 1 square inch consists of 1,000 feet horizontally and

TABLE III

Observed Values				Calculated Values				
Sta.	Dist. s	Dip, a	Elev. E	Tan a	E Tan a	Sin a	Dist. x	Sta.
	Feet		Feet		Feet		Feet	
A........	0	$+20°$	0	$+.364$	0	$+.342$	0	A
B........	1,600	45	$+700$	1.000	$+700$	.707	900	B'
C........	2,800	60	800	1.732	1,385	.866	1,415	C'
D........	3,400	70	200	2.748	550	.940	2,850	D'
F........	5,200	-40	-300	$-.839$	250	$-.643$	4,950	F'
G........	6,300	$-20°$	$+400$	$-.364$	-145	$-.342$	6,445	G'

0.5 vertically, or 1 square inch = 500 feet. Therefore the thickness exposed between O and D' is 4.40×500, or 2,200 feet. This is represented by the definite integral T_1 above. To this must be added the thickness of strata between D' and exposure D, which is equivalent to $E/\cos a$ or $200/\cos 70$, making 585 feet. Therefore the total exposed thickness is $2{,}200+585$, or 2,785 feet.

As an example to show how the plus and minus signs are used, we may compute the thickness exposed between O and exposure F. The thickness between O and F', the perpendicular projection of F, is found from Figure 3B by taking area $AD'MO$ minus area $MF'L$, or 6.40 square inches $-$ 0.37 square inch = 6.03 square inches. Since 1 square inch is 500 feet, the thickness exposed to F' is 6.03×500, or 3,015 feet. The correction for elevation is $E/\cos a = -300/\cos(-40) = -390$ feet. Hence the total thickness between O and exposure F is $3{,}015-390$, or 2,625 feet.

CASE IV. STRATA HAVE LOW DIPS, UNDER 10°, WITH EXPOSURES AT ANY ELEVATION

The method of graphical integration is especially useful in determining thicknesses in regions of low dips. In such cases it is immaterial whether the similar or parallel law is used, as the sines and tangents of angles up to 6° are nearly the same, and close enough for ordinary purposes for dips up to 10°. Also, the correction for elevation is simple, being merely the addition or subtraction of the elevation referred to some datum plane.

The following example will suffice to illustrate this case. The section is about $2\frac{1}{2}$ miles long, the dips being flat or as much as 10°. The exposures are reduced to the same elevation in the case cited, and the parallel law used. Table IV shows the nature of the section.

TABLE IV

Station	Distance, x	Dip, a	Sin a
	Feet		
A	0	+10°	+.174
B	1,400	7	.122
C	3,800	4	.070
D	5,500	2	.035
E	7,200	0	000
F	8,000	−2°	−.035
G	9,000	0	000
H	10,000	+3	+.052
I	12,000	1	.018

For the calculations, in drawing the curve for determining the areas, the sines were plotted on the vertical scale so that 1 inch was equivalent to 0.05, and the distances on the horizontal scale so that 1 inch equaled 1,000 feet. One square inch of area was therefore the same as 50 feet of formation thickness. This curve showed the probable synclinal axis at a distance of 7,200 feet from A, and the anticlinal axis at a distance of 9,000 feet, as would be indicated by the figures in the table. The thicknesses worked out as in Table V.

The negative thicknesses indicate reversed strata. The figures show that with reliable dips close results are obtainable by the method described.

CURVE FOR ESTIMATING DIPS WHERE THERE ARE NO EXPOSURES

The sine and tangent curves given in the preceding cases are useful to estimate the probable dip at some point where no exposures are available. Another means of obtaining the same end is to plot

TABLE V

Thickness	Feet
A to *B*	+210
B to *C*	221
C to *D*	90
D to *E*	30
E to *F*	− 14
F to *G*	− 23
G to *H*	28
H to *I*	+ 87

the actual dips in degrees vertically against the distances laid off horizontally. In order to insure uniformity, the latter is the method to follow in case both the sine and tangent curves are used in the same section (as might sometimes happen), interpolations from the degree curve being used to round out the trigonometric curves.

THE WELSH, LOUISIANA, OIL FIELD[1]

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ABSTRACT

The Welsh oil field seems probably to be of the Goose Creek or non-salt-dome type of Gulf Coast oil field. The beds are relatively flat over the field, but dip sharply to the southwest in the southwest quadrant. Small production was developed from the Pliocene, but failed after several years, so that today there is no production at Welsh. The oil was of low gravity, 11° to 19° Baumé, but had especially high fire and flash points and a viscosity that made it especially desirable for car-journal oil. The field has some possibilities for discovery of deeper productive sands.

INTRODUCTION

LOCATION

The Welsh field is in Jefferson Davis Parish, southwestern Louisiana, about 3 miles west of the town of Welsh on the Southern Pacific Railroad, in sections 21, 22, 27, and 28, T. 9 S., R. 5 W. The developed portion is confined to the southeast quarter of Section 27 and the southwest quarter of Section 22.

PREVIOUS WORK

Comparatively little has been published on the Welsh field, and great difficulty has been experienced in obtaining well logs or reliable information on the history, development, and even the location of the wells in the field. This is explained by the fact that the operations were carried on, in the main, by individuals and small companies. Of the published literature, the writings of Harris are the most complete.[3] The only other data of real value have been obtained through the courtesy and co-operation of some of the oil companies in Houston, especially of The Texas Company, and the Rio

[1] Published by permission of Mr. E. T. Dumble, consulting geologist, Southern Pacific Company.

[2] Geologist, Rio Bravo Oil Company.

[3] G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Surv. Bull., 429,* 1910; also *U. S. Geol. Surv. Bulls. 212,* p. 136, 1903, and *282,* pp. 102–5, 1906; and *Report La. Geol. Survey,* 1907, p. 35.

Bravo Oil Company, which made available several well logs, production data, and reports made by William Kennedy.

HISTORY

The discovery of Spindletop, near Beaumont, Texas, in January, 1901, brought about a search for similar structures throughout the Gulf Coast, and every topographical high was suspected of being a possible salt dome. During the following year this prospecting brought about the discovery of Anse La Butte, Jennings, Welsh, and Humble domes, and subsequently there were a number of others.

The surface indications suggestive of a dome at Welsh were a slight topographic elevation and a gas seep in a shallow water well on the Woods farm, located on the elevation. In the latter part of 1901, the Welsh Home Development and Oil Company drilled the first well on Lot 3, Block 6, Woods subdivision, southeast quarter of Section 27. This well was drilled to 1,050 feet. The hole was ruined, but the showings encountered warranted further development. The following year the same company had a blowout of sand from their well No. 2 at 1,000 feet. From that time the field was considered more seriously, but drilling activity has never been undertaken on a large scale.

The development has been intermittent all through the life of the field. From 1901 to 1910, according to reports made by William Kennedy to the Rio Bravo Oil Company, some 40 wells were drilled in the field within a radius of 2 miles. Since 1910, it is estimated that some 51 more wells have been drilled, making approximately 91 wells for the entire field to date.

Among the first producers was well No. 1 of the Southern Pacific (now Rio Bravo Oil Company), which was brought in January 2, 1903, at a depth of approximately 1,010 feet. This well continued producing until January, 1911. During that period it yielded a total of 72,000 barrels of oil.

The greatest production according to figures taken from *Mineral Resources of the United States*, was obtained in 1910. Since that year the production has gradually declined to almost nothing and virtually ceased in 1917. The wells have been pumped occasionally for local consumption. A few dry holes have been drilled since 1917, mainly deep tests. Two wells, 3,100 and 3,315 feet, were put down south of the railroad in the southeast quarter of Section 27. The deeper, Avery and Martin, well blew considerable gas from about 1,600 feet. In 1921 the Gulf Production Company drilled two deep wells, one north and the other northeast of the field. In 1923, Lucas *et al.* drilled a 3,200-foot hole on the southwest edge of the field. These tests were all dry. Hooks *et al.* are now drilling on the southwest edge of the proven area and are at present testing a sand at 1,758 feet. This sand is deeper than previous production and is reported to have given a promising showing.

TOPOGRAPHY

The country about Welsh is a featureless plain except for the slight elevation which called attention to possibilities of oil. At the

field the elevation is 24 feet above sea-level, and there is locally as much as 10 feet relief. Figure 1 shows that there is an appreciable slope to the south and west. The crest of the hill is about 1 mile north of the field, where the rocks take a gentle dip to the north. Branching to the east from this hill is a decided ridge which crosses the railroad and then broadens out to form a low upland covering a relatively large area. On the east side of the ridge there are at least two distinct terraces, which have probably been caused by the slough that now has its channel about 2 miles east of the field.

STRATIGRAPHY

The Welsh field is in the wide belt known as the Gulf Coastal Plain, and the surface is composed of Beaumont clays. The well records show the thickness of these surface clays in the field to vary from 60 to over 200 feet, and they appear to lie unconformably upon the series of beds assigned to the Lafayette.

A general section typical of the field obtained from various logs shows about 100 feet of clay above the sands and gravels of the Lafayette formation, which, with partings of shale or gumbo, is taken to be about 800 feet in thickness. Downward from this depth there is probably a gradation into lower beds of the Pliocene.

Several oil sands, most of them shallow, are found in this field. As a rule, the wells obtained production from the first sand, as it has appeared to contain less salt water than the deeper ones. In the center of the field this horizon is 960 to 1,010 feet below the surface. Although a few higher and lower sands gave showings, the horizon mentioned is the main one.

The zone containing oil sands lies below the gravels and belongs either in the upper Pliocene or in transition beds. On account of the manner in which the wells were drilled at that early period, and the inadequate records kept, only a general conception of the actual character of the formations can be gained.

Some of the wells in the field have a thin "cap rock" immediately overlying the first oil sand. This rock is not the true cap rock found so often in the salt domes, but is merely a local induration of the sand caused by cementation. It varies from 1 to 6 feet in thickness and is sometimes merely a shell, and does not occur at a definite horizon.

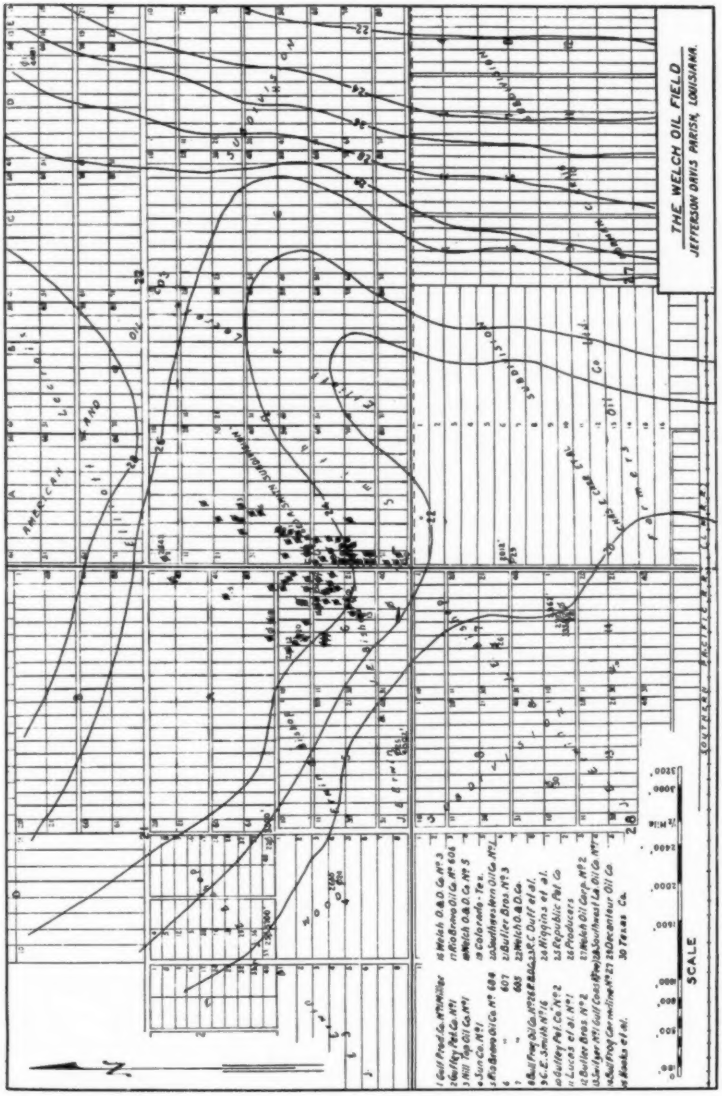

FIG. 1.—Topographic map of the Welsh oil field. Datum mean sea-level

There is doubtless considerable lensing of the sands and a gradation of sands into shales. It was established, however, that a more or less uniform zone to be relied upon for oil-bearing sands is present. Immediately overlying the sand when the thin cap is absent, or directly above the cap when present, is a bed of gumbo varying from 60 to 80 feet in thickness. This gumbo bed appears to be more uniform than the sand itself, and was used by the drillers as a marker.

Although the sand seems to be irregularly distributed throughout the field, with a thickness of 10 to 15 feet, it is thickest as a rule in the central portion, where it averages 20 feet.

The quality of the sands, like the thickness, varies in different wells, but the texture is fairly regular. Mr. Kennedy found the sand to be a white, translucent quartz of fairly even grain, angular, but with the sharp corners worn off. About 90 per cent remains on a 60-mesh screen, and half of the remainder will not pass the 80-mesh. While a little of the sand is very fine, it will not pass through the 120-mesh. From a test of the voids in the sand, it was estimated by Mr. Kennedy to have an oil capacity of 25 per cent. Some of the deeper sands that gave showings of oil were found to be extremely fine-grained and angular.

PALEONTOLOGY

A number of beds containing shells are mentioned in the logs, which should have thrown more light on the stratigraphy had the fossil beds been cored or specimens collected, but the only paleontological evidence remaining consists of a few bivalve shells from the Guffey, Rio Bravo well No. 605 and the Gulf Coast well. Of these, only one or two were sufficiently intact to be identified, and of the lot it may be said that the species are too long ranging to be of any assistance in determining the age of the formations. The list is as follows:

Rio Bravo Oil Co. well No. 605, 1,585–1,589 feet
Rangia cuneata Gray
Mulinea lateralis Say
Rangia (?) *quadricentennialis* Harris

1,642–1,648 feet
Rangia fragments

1,817 feet
Rangia fragments
Guffey well, 1,800 feet
Rangia sp. ?
??, 1,390 feet
Rangia cuneata

Five cores of sands from various depths were recently secured from the well being drilled by C. G. Hooks *et al.* These cores were examined by E. Richards Applin, paleontologist for the Southern Pacific Company, who reports as shown in Table I.

TABLE I

Depth	Formation
1,355 feet	Core of dark gray, very fine-grained sand. Sand grains even in size and angular. A few, possibly 10 per cent, of the sand grains dark green and gray in color. No foraminifera or indications of other fossils. Good oil show.
1,400–1,500 feet	Core of extremely fine, even-grained, light-gray sand, with a few worn fragments of some fossil shell. A very few small nodules of pyrite. Slight oil show.
1,500–1,600 feet	Core of extremely fine-grained gray sand which contains at least 25 per cent of very fine fragments of finely splintered volcanic glass. Slight oil show.
1,616 feet	Core of sand as described at 1,400 feet but slightly coarser. Slight oil show.
1,758 feet	Core of material like above. Nothing to indicate its age. Slight show of oil.

The absence of Foraminifera, and especially the reworked Foraminifera so characteristic of the Miocene, strengthens the belief that the Pliocene still prevails at this depth.

STRUCTURE

There have been a few unsatisfactory deep tests made at Welsh, some on the structure, but the majority either on the flanks or entirely away from it. The wells are tabulated as shown in Table II.

None of the deeper wells reached salt, nor did they encounter structure peculiar to the typical domes where the salt core approaches the upper horizons. The log of Welsh No. 3 shows about 200 feet of rock or limestone, as indicated in the accompanying sec-

tion, but no other well in the area records more than thin breaks of rock. Welsh must be classed, therefore, with such fields as Goose Creek, Orange, and Edgerly, until more thorough and deeper prospecting justifies a change in its status.

After plotting the logs for the two cross-sections of the field as shown in Figures 3 and 4, it was found that the only datum plane that could be used was the first oil sand, as no other formation was uniform enough to be correlated. Even this horizon has proved to be rather unsatisfactory, although immediately overlain by a fairly constant bed of gumbo which could be used in conjunction and as a

TABLE II

Company and Well	Location	Subsurface Contour	Depth (Feet)
Producers Oil Co.	Lot 26, Block 7, Sec. 28, SW. of field	....	2,860
Republic Prod. Co.	Lot 36, Block 5, Sec. 21, SW. of field	Contour 1,250	4,002
Producers Oil Co.	S. of railroad track	....	3,000
Guffey Pet. Co. No. 1	Lot 1, Sec. 22, N. of field	Contour 1,000	2,542
Guffey Pet. Co. No. 2	Lot 71, Sec. 22, S. of field	Contour 1,025	2,446
Gulf Prod. Co. No. 1 Wright	Sec. 9, 2½ mi. N. of field	Contour 1,875?	3,511
Gulf Prod. Co. No. 1 Miller	Sec. 22, 1 mi. NE. of field	Contour 1,640?	4,481
Rio Bravo Oil Co. No. 605	Lot 43, proven area	Contour 975	2,640
C. E. Smith	Lot 6?, Block 6, Sec. 21	Contour 1,000	2,800
Lucas *et al*	Lot 19, SE. edge of proven area	Contour 975	3,200?
Hooks *et al*	Lot 22, SE. edge of proven field	Contour 1,000	Drilling
Welsh Oil & D. Co.	Lot 40, Block 1, NW. of field	....	3,500
R. C. Duff *et al*	Lot 37, Block 1, NW. of field	....	3,700
Higgins *et al*	Lot 4, Block 4 W. of field	....	2,640
Avery & Martin, Todd No. 1	SE. quarter, Sec. 27	....	3,100
Welsh Oil & D. Co. & Getty	SE. quarter, Sec. 27	....	3,315

check to give the interpretation of the subsurface structure presented.

From the evidence available, the more abrupt dips appear to be to the southeast and southwest. Additional data may change this conclusion. The rate of dip appears to be somewhat as follows:

Center to north at the rate of 143 feet per mile
Center to east at the rate of 264 feet per mile
Center to south at the rate of 1,000 feet per mile
Center to west at the rate of 417 feet per mile

From data obtained by the well logs both in the field and on its edges, as shown by the subsurface contours and also by the varying thickness of the Beaumont clays, it is apparent that the upward movement has been of slight degree and intensity. The wells quite distant from the field are reported to have encountered surface beds

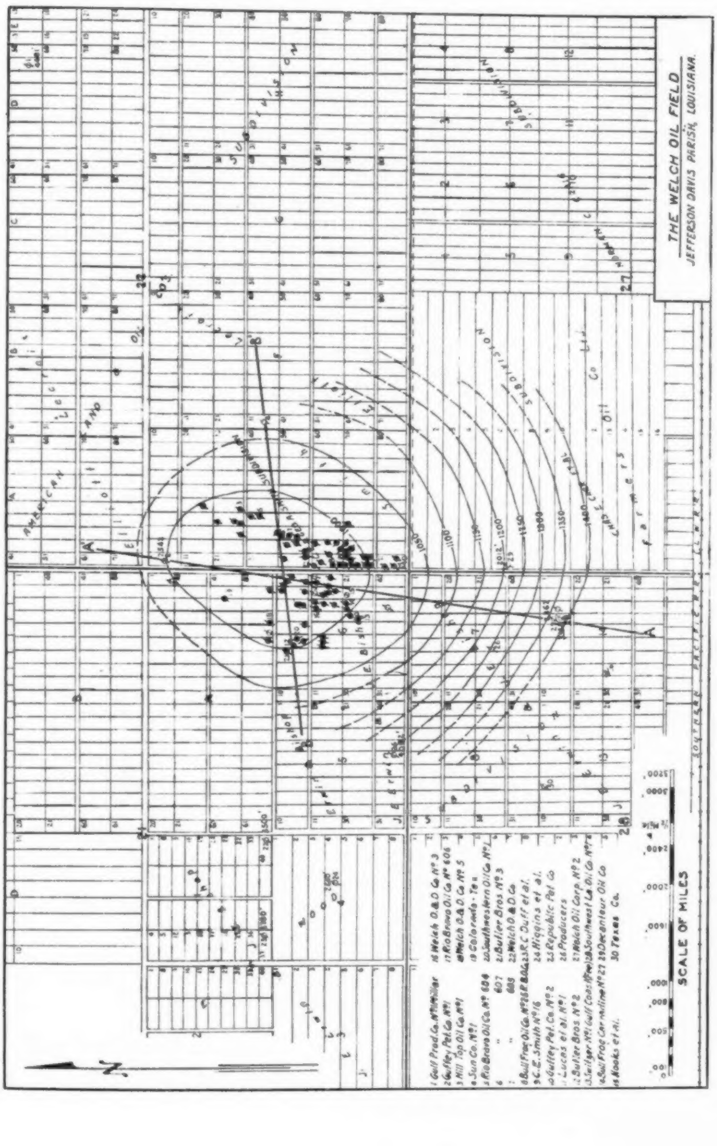

FIG. 2.—Structure contour map of the Welsh oil field. Contours on the producing horizon

of clays 200 feet and more in thickness, while within the producing area these clays are much thinner. Mr. Kennedy states that there is an

overlying deposit of yellowish clay varying in thickness from 63 feet in the Rio Bravo Oil Company well to 105 feet in the Welsh Company No. 3 and 104 feet

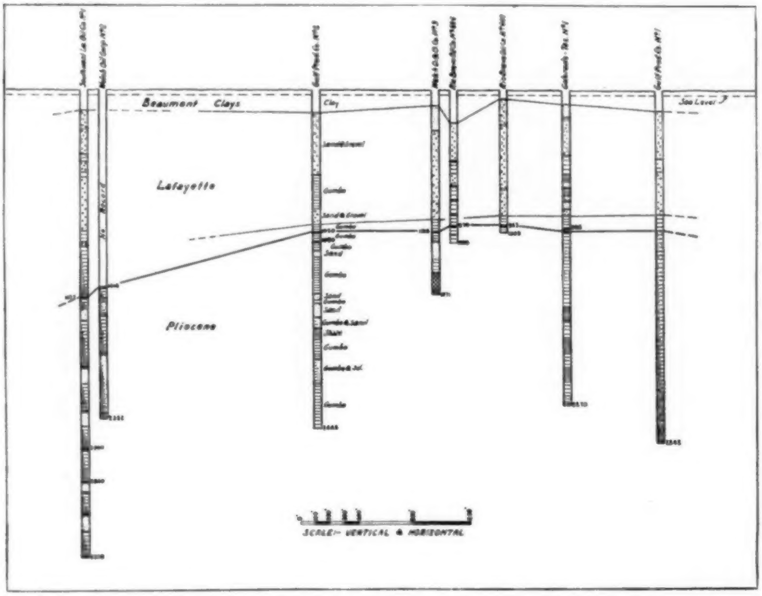

FIG. 3.—North-south structure section through the Welsh oil field, along line A–A' of Figure 2.

in the Rio Bravo No. 1. At the western or southwestern end of this ridge the clays thicken to 200 feet and more and the same condition appears to exist toward the northeast.

It thus appears that there has been movement subsequent to the deposition of the Beaumont clays. If there had been movement prior to this, the Lafayette formation should be noticeably thinned toward the top of the dome, but if this is the case, it cannot be detected from the well records. The thinning of the Beaumont clays is not of great amount, and the fact that the elevation still appearing

at the surface has not been entirely eroded to the level of the surrounding plains is indicative that the movement has been of recent date, or that there has been subsequent movement, possibly still in progress.

The sands that furnished the major production were at the 1,000-foot horizon, were of relatively flat contour, and lay just below

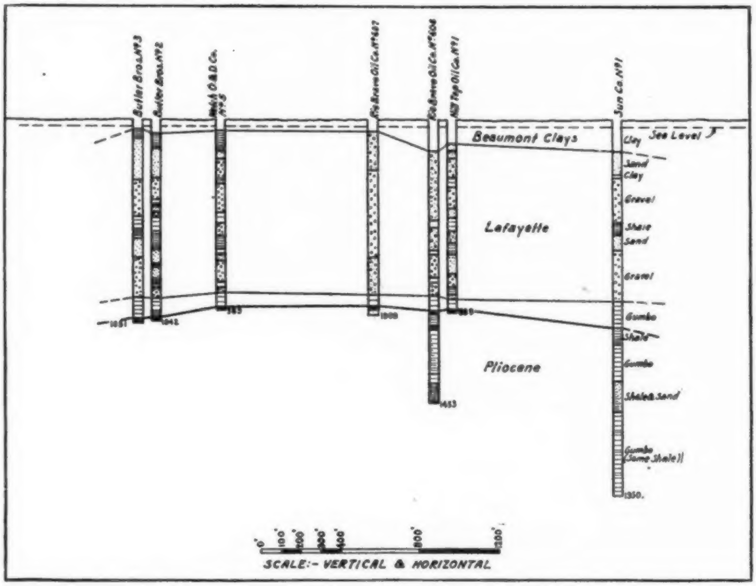

FIG. 4.—West-east structure section through the Welsh oil field, along line *B-B'* of Figure 2.

gravel beds of Upper Pliocene age. The deeper drilling, both of early and late years, has furnished no positive evidence of either lithologic or paleontologic nature to indicate that the Lower Pliocene has been penetrated and the possibilities of the Miocene explored.

The relative flatness of the known oil horizon and the surface evidence furnished by the thinning of the Beaumont clays indicate that the slight doming of the upper strata may be only the reflex of more pronounced movements at greater depths. It is possible, there-

fore, that the lower formations may be found in a much more characteristic state of dome structure, and the deep sands, under these circumstances, may be reservoirs.

OIL AND GAS

Gas is found in the same sand as the oil, and at times under considerable pressure. The first serious blowout occurred in the second well drilled. Since then, several wells have blown gas with quantities of sand. The pressure was quickly exhausted, however, and there were no wells in the field classifiable as gas wells.

Only the upper portion of the sand contains oil, the lower part being filled with salt water. Most of the wells flowed for a few days when brought in, some as much as 200 barrels per day, but this initial production quickly settled down to about 15 barrels on the pump. Two wells are reported to have produced for five years, and well No. 1 on the Rio Bravo for eight years. As a rule, however, the wells did not have a long life and usually had to be abandoned within a year, as may be seen by production curves for the individual wells (Fig. 6).

Mr. Kennedy states that the oil from the Welsh field is characterized by its heavy gravity, dark color, and the faculty of retaining water in an emulsified form longer than the oils from other Coastal fields. From 14 to 21 per cent water remains in the oil until separated mechanically, the separation being fairly readily performed. At times a little fine-grained sand is found in the fluid.

The oil is all of low gravity, but it varies in different parts of the field, the comparatively lighter oil being found in the central portion. Oil from the McFadden well (near the margin) had a gravity of 11.5° Baumé, the Central City well near by, 12° Baumé, while wells of the Rio Bravo, near the center of the field, had a gravity of 17.5° to 19.9° Baumé. When the water is extracted, oil of 17.5° Baumé has a gravity of 19.5° to 23.5° Baumé. This oil has a turpene base.

Oil when freed from water and having a gravity of 19.5° Baumé showed a flash point of 225° F. and burning-point of 275° F. The viscosity as compared with oil from Spindletop at a temperature of 70° F. is demonstrated in a comparative test of these two oils as shown in Table III.

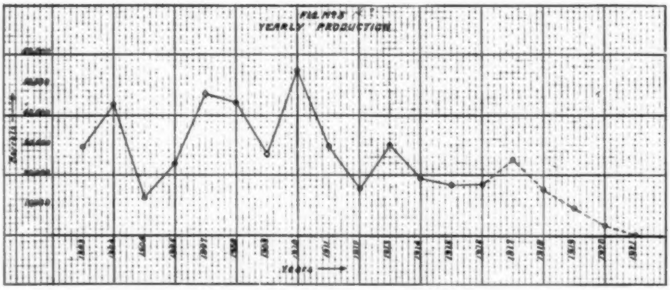

FIG. 5.—Curve of production by years for the Welsh oil field

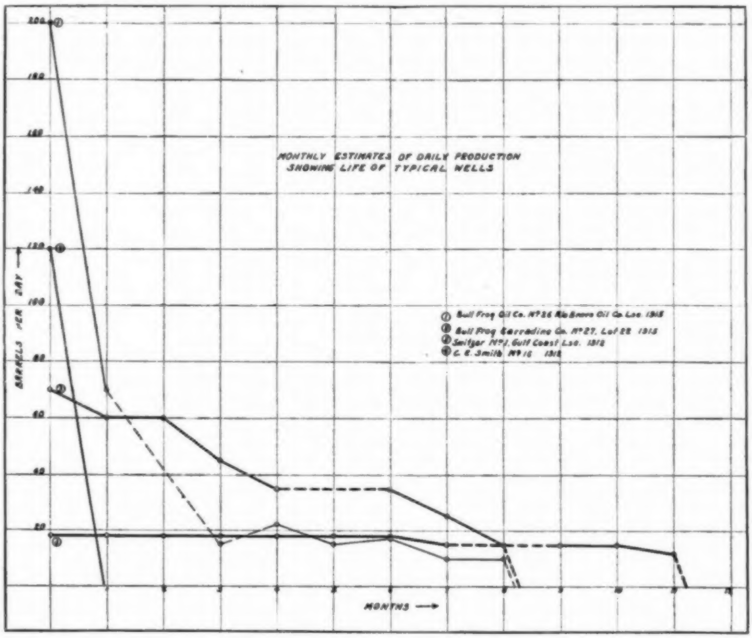

FIG. 6.—Curves of production by months for the Rio Bravo Oil Co., Bull Frog Oil Co. No. 26, the Bull Frog Carradine Co. No. 27, the Gulf Coast Oil Co. Switzer No. 1, and C. E. Smith No. 16.

During the years that Welsh was productive, a large percentage of the production was used by the Southern Pacific Railroad for journal oil. Owing to the high flash point, high fire point, and the high viscosity, it was very desirable for that purpose.

DRILLING METHODS

Rotary drilling-rigs similar to those employed in the early days in all Coastal fields were used at Welsh, and they were used in the same carefree manner that characterized drilling operations at that period.

PRODUCTION DATA

Figures for yearly and monthly production and for completions are obtainable from the annual reports of the *Mineral Resources of*

TABLE III

	Spindletop Oil	Welsh Oil	Galena Engine Oil
Gravity	22° B.	19.5° B.	25.2° B.
Flash point	180° F.	255° F.	
Fire point	200° F.	255° F.	
Viscosity at 70° F.	1	8.17	4.65

the United States. After 1917, Welsh produced so little oil that its production has not been listed separately; so from that year, only estimated figures can be given. What has been pumped from the one or two wells since 1919 has been readily consumed for fuel by the local rice farmers. Up to 1917, the oil bought or produced from the Welsh field was piped by the Rio Bravo Oil Company to a siding near the field and run through a cleaning-plant before being used for car-journal oil. Curves have been plotted for yearly production and for the yield of characteristic wells (Figs. 5 and 6).

FUTURE OUTLOOK

From the fact that the production of this field in the upper horizons has been practically exhausted, and from the fact that the few deep tests made in the past have offered little or no encouragement,

this field has lain dormant, and the general impression prevails that it is a closed chapter in oil history.

An analysis of the evidence and production so far obtained and an analysis of the operations in the past, viewed particularly from the standpoint of modern methods of testing cores of sands, leaves the results of the deep tests made in the past open to doubt as regards determinations of the oil-producing possibilities of the sands encountered.

The hypothesis is certainly admissible that the Lower Pliocene or Upper Miocene sands, when explored by modern methods, as at Orange, will probably approach more typical and favorable conditions for accumulation of oil and gas; and it is believed that the occurrence, quantity, and quality of the oil and gas so far recovered (apparently from Upper Pliocene sands) is indicative of larger and deeper deposits. See Table IV.

TABLE IV

ANALYSIS OF PETROLEUM FROM WELSH, LOUISIANA

Color	Olive Green
Odor	Pleasant
Specific gravity	19.2° B. at 60° F.
Viscosity	36.8°
Naphtha	1.05 per cent
Illuminating oil	30.07 per cent
Lubricating oils	65.38 per cent
Coke, gas, and loss	3.50 per cent
	100.00

F. C. Thiele, Beaumont, Tex., analyst. This oil is entirely free from sulphur.

TABLE V

List of Wells in the Welsh Field, Jefferson Davis Parish, Louisiana

Company	Well		Total Depth (Feet)	Oil Sand (Feet)	Initial Production	Date Completed	Remarks
......	Hilltop	No. 1	960	960	Small	......	7 ft. of oil sand
......	Hilltop	No. 2	960	960	12 bbls.	......	Junked
......	Hilltop	No. 3	960	960	8 bbls.	......	
......	Hilltop	No. 4	960	960	Small	......	
Southern Pacific Co.	S. P.	No. 1	1,006	1,006	......	......	
Southern Pacific Co.	S. P.	No. 2	970	970	......	......	Abandoned producer
Southern Pacific Co.	S. P.	No. 3	970	970	......	......	Dry hole
Metropolitan Co.	Metrop.	No. 1	996	996	23 bbls.	......	Junked
Welsh O. & D. Co.		No. 1	1,050	1,050	......	......	Abandoned producer
Welsh O. & D. Co.		No. 2	1,050	1,050	......	......	Abandoned producer
Welsh O. & D. Co.		No. 3	1,100	1,100	None	......	Blew out at 1,100 ft.
Welsh O. & D. Co.		No. 4	1,020	1,020	50 bbls.	......	Pumped
Southwestern O. Co.		No. 1	1,020	1,020	Gas	......	Gassed 3½ hours
Boss-McFadden		No. 1	1,030	1,030	......	......	
Texas Co.		No. 1	1,200	1,200	None	......	Dry hole
Decatur O. Co.		No. 1	2,012	1,140	None	......	Dry hole, oil at 1,400 ft.
Colo.-Tex		No. 1	2,340	1,000	......	......	Abandoned producer
Brown-Lively		No. 1	1,100	1,100	None	......	Dry hole, no oil
Taber		No. 1	1,025	1,025	......	......	
Welsh O. & D. Co.		No. 5	2,000	1,800	None	......	Dry hole, 200 ft. oil sand
......	Butler	No. 1	1,350	1,350	......	......	Abandoned producer
......	Butler	No. 2	1,350	1,350	40 bbls.	......	Abandoned producer
......	Butler	No. 3	1,350	1,350	......	......	Abandoned producer
Liberty S. & O. Co.	Liberty	No. 1	1,360	1,350	......	1918	Abandoned producer
Liberty S. & O. Co.	Liberty	No. 3	1,340	1,340	......	1919	Show of oil
Crescent O. Co.	Crescent	No. 2	1,350	1,350	......	1919	Show of oil
Liberty S. & O. Co.	Liberty	No. 2	1,345	1,345	......	1919	Show of oil
Crescent Oil Co.		No. 1	1,340	1,340	......	1918	Show of oil
Crescent Oil Co.		No. 3	1,350	1,350	......	1919	Show of oil
Crescent Oil Co.		No. 4	1,360	1,360	......	1919	Show of oil
Scoggins, Jeter & Hackworth		No. 1	1,050	1,035	Small	1920	Pumping intermittently
Bull Frog O. Co.		No. 1	940	940	......	......	
Bull Frog O. Co.		No. 2	950	950	......	......	
Metropolitan		No. 3	940	940	......	......	
Southern Pacific Co.		No. 4	950	950	......	......	
Metropolitan Co.		No. 2	940	940	......	......	
Simms Oil Co.		No. 1	2,000	......	......	......	
Republic Prod. Co.		No. 1	......	......	......	......	
R. C. Duff *et al*		No. 1	......	......	......	......	
Welsh Oil Corp.		No. 1	......	......	......	......	
Welsh Oil Corp.		No. 2	2,397	......	None	1917	No show of oil
Guffey		No. 1	......	......	......	......	
Guffey		No. 2	......	......	......	......	
Scoggins, Jeter & Hackworth	......		......	......	......	......	
Liberty S. & O. Co.		No. 4	......	......	......	......	
Flying Dutchman O. Co.		No. 1	1,340	1,330	None	1917	No show of oil
......	Spindletop	No. 1	1,700	......	None	......	Show of gas at 1,000 ft.
......	Wildcat	No. 1	......	......	None	......	No trace of oil
Smith, Switzer, *et al*	......		1,600	......	None	1910	Reported that the driller said the formation was very much broken up and he did not go deeper on this account. Exact location not determined
Sun Co.		No. 1	......	......	......	......	
Higgins Oil & Fuel Co.		No. 1	......	......	......	......	
Central City		No. 1	......	......	......	......	
Central City		No. 2	......	......	......	......	
Central City		No. 3	......	......	......	......	
Peter Lamp		No. 1	......	......	......	......	
S. Keoughan		No. 1	......	......	......	......	
Ala.-Southwestern		No. 1	......	......	......	......	
Ala.-Southwestern		No. 2	......	......	......	......	
Ala.-Southwestern		No. 3	......	......	......	......	
Gulf Prod. Co.	Miller	No. 1	......	......	......	......	
Gulf Prod. Co.	Wright	No. 1	......	......	......	......	

Total, 61 wells.

THE SULPHUR SALT DOME, LOUISIANA

P. K. KELLEY
Houston, Texas

ABSTRACT

The sulphur salt dome in Louisiana is a typical Gulf Coast salt dome, but is exceptional in its small area, about 75 acres, in the very great thickness of the cap, about 1,000 feet, and in the richness of its deposit of native sulphur. The cap is composed of anhydrite and a mantle-like mass of "lime" rock covering the top and flanks of the anhydrite. The sulphur is found as a secondary mineral in the transition zone between the "lime" rock and the anhydrite and has probably been precipitated from hydrogen sulphide or metallic sulphides in solution. After a long history of vain expensive attempts to mine the sulphur, the Frasch process was perfected, by which the sulphur is melted in place and pumped in liquid form to the surface. The total production to date has been about 9,000,000 tons of sulphur with a gross value of $150,000,000. Small amounts of heavy oil were encountered in the early sulphur wells, but not in commercial quantity. The flanks have not been well tested for oil.

INTRODUCTION

LOCATION

The salt dome in Calcasieu Parish, Louisiana, operated for sulphur by the Union Sulphur Company, is in the north half of Sec. 29, T. 9 S., R. 10 W. It is $\frac{1}{2}$ mile north of the main line of the Southern Pacific Railroad, $\frac{1}{4}$ mile from the Old Spanish Trail highway, and 6 miles from the Kansas City Southern Railway. The nearest town is Lake Charles, 13 miles to the east. The village of Sulphur is $2\frac{1}{2}$ miles distant. The sulphur mine is served by a short railroad line, the Brimstone Railroad and Canal Company, which connects the property with the two lines.

HISTORY

The locality first attracted attention because of a petroleum seep. Just before the Civil War, Dr. Kirkman, a local physician, drilled a well in the southeast corner of Section 19. This location happened to be some 1,500 feet away from the dome. In spite of primitive methods, he pushed down to below 450 feet, where gravel stuck his pipe and put an end to the enterprise.

After the war, the Louisiana Petroleum and Coal Oil Company drilled a well 1,230 feet deep into the cap rock, a log of this test given by Hilgard and Harris[1] being as follows:

[1] G. D. Harris, *U. S. Geol. Surv. Bull. 429* (1910), p. 100.

TABLE I

LOG OF WELL OF LOUISIANA PETROLEUM AND COAL OIL COMPANY

Feet	Thickness in Feet	Depth in Feet
Yellow and blue clay	160	160
Gray and yellow sand	173	333
Lime rock at	....	333
Blue sandy limestone	50	383
White crumbling limestone	65	448
Pure sulphur	203	651
Gypsum containing sulphur	39	690
Gypsum containing large percentage of sulphur	440	1,130
Gypsum containing sulphur	100	1,230

After discovery of the sulphur, various efforts to exploit it were made. A company financed in France undertook to sink a shaft to the mineral. Elaborate equipment, including large-diameter iron caisson in sections, was shipped from France, unloaded on the west bank of Calcasieu River, whence it was hauled, dragged, and rolled to Sulphur Mine. Before all the rings had left the river bank, the shaft encountered quicksand and filled up with water and hydrogen sulphide gas. After several men working in the bottom of the excavation had been killed, the French syndicate quit, with a loss of nearly a million dollars. Nothing remains of their enterprise but one of the huge iron rings, which is still reposing on the bank of Calcasieu River with a pine tree 2 feet in diameter growing through the middle of it.

Some years later the American Sulphur Company undertook the same work with more modern methods. After many vicissitudes and the expenditure of a large sum of money, they found themselves fighting a losing battle with quicksand and went for advice to Mr. Herman Frasch, a chemical engineer of wide experience, especially in the fields pertaining to the refined products of petroleum and salt. In 1892 Mr. Frasch conceived the idea of melting the sulphur in the ground and pumping it out as a liquid. The property had lain idle after the various ineffectual attempts to develop it and was not regarded as much of an asset by its owners, at that time the Louisiana Sulphur Mining Company of New Orleans. Negotiations by which the Union Sulphur Company acquired title were completed in 1893, and Mr. Frasch started work on his problem. Drilling and experimental equipment uncovered many unsuspected problems, both in the physics of the method and in the geology of the deposit and necessitated endless changes in the mechanical devices applied to the exploitation of the sulphur. After ten years of discouragement, the property was put on a commercially producing basis by means of what is now known as the Frasch process. No history of this operation, however short, can be complete unless it includes a tribute to the courage and perserverance of Herman Frasch, the father of the American sulphur industry.

Since 1903, the property has been in successful commercial operation.

PHYSIOGRAPHY

An attempted restoration of the principal topographic features of the district to conditions before changes effected by the mining operations of the Union Sulphur Company is given in Figure 1.

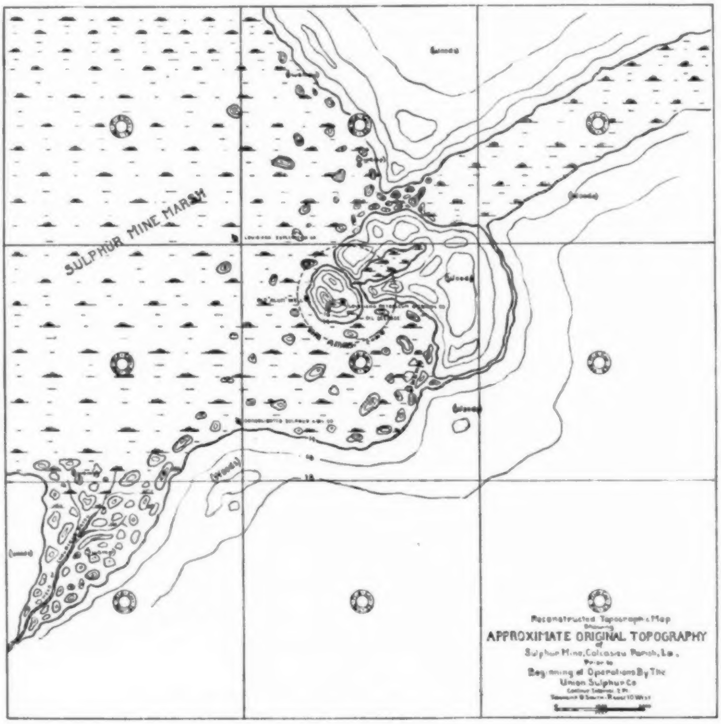

FIG. 1

Before the surficial irregularities of the region were rendered less apparent by artificial drainage, a magnolia-studded ridge, later called Sulphur Mine, projected southward from the southern edge of the piney woods into Sulphur Mine marsh. This marsh, now drained and tilled, was formerly a shallow intermittent lake, some 8,000 acres in area, grown up with lush bamboo. The ridge itself

was not high. The Marsh level is 14–15 feet above sea-level, and the highest portion of the ridge was not over 7 or 8 feet above the marsh.

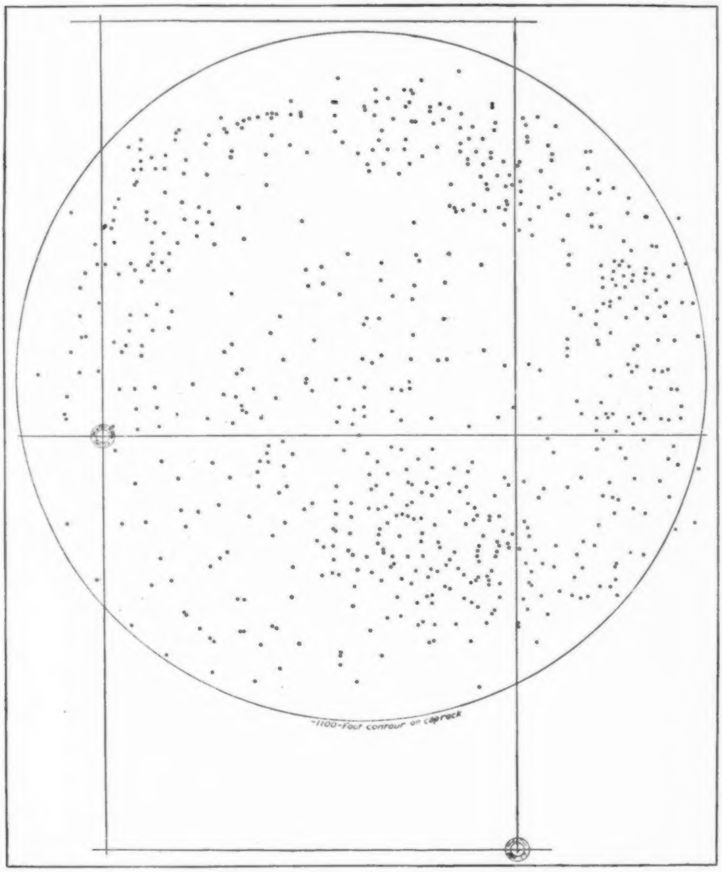

FIG. 2.—Map of wells drilled on the sulphur salt dome, Sec. 29, T. 9 S., R. 10 W., Calcasieu Parish, Louisiana.

Two peculiarities distinguished this ridge. The first was a petroleum seep or spring, the position of which is indicated in

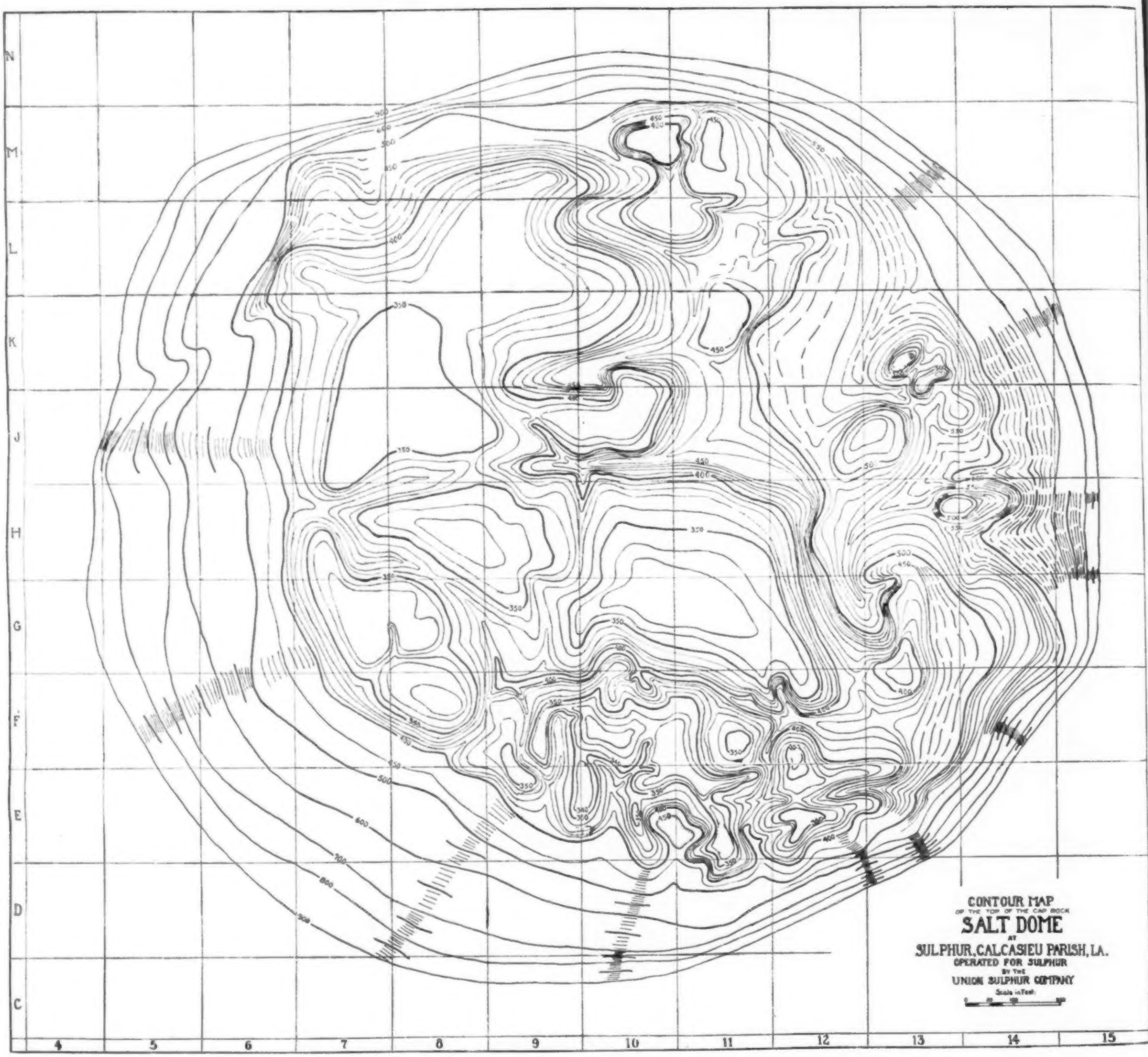

Fig. 3—Topography of the cap rock at Sulphur. Contours below sea-level

Figure 1. This seep was perennial and was not affected by rainfall. The volume of fluid was very small. The second was an "alum well," or seep, at the edge of the marsh, on the extreme western side of the ridge. There is no record of any analysis of this water. No oil accompanied this flow, but there was some gas. Its astringent quality was no doubt due to a small admixture of sulphuric, or, more probably, sulphurous acid. The water oozed to the surface over a soft, mucky, grass-covered place some 12 or 15 feet in diameter.

GEOLOGY

Sulphur Mine has the smallest cap-rock area of any of the coastal domes. At 1,100 feet below sea-level its area is approximately 75 acres. It is almost perfectly circular in plan.

Figure 2 shows the wells drilled to date, 661 in number. The large number of wells drilled into the cap rock makes possible a contour map of the dome top, graduated to a smaller scale than usual. Contours on the top of the cap rock are shown in Figure 3; they are accurate in a general sense, but may vary from the original form of the cap rock to the extent that the figures supplied by more recently drilled wells are affected by possible subsidence, due to the removal of the underlying sulphur.

A typical well log, from the surface to the top of the cap, shows an ordinary section of blue, yellow, and red clays, alternating with sandy clays and sands, to about 250 feet (Beaumont clays), where a fine water-saturated sand is encountered, and then Lafayette gravel to the cap rock. The elevation of the top of these gravel beds is affected very little, if any, by the upthrust of the dome immediately below them; on the flanks of the dome, however, they are from 100 to 300 feet thicker than on the top. This situation suggests the possibility that the top of the dome was exposed at the surface, during a part of Lafayette time. The writer has examined hundreds of cores from this cap rock, but no fossils have been found. There has been insufficient drilling around the sides of the dome to supply paleontological evidence, should any exist, as to the period or periods in which uplift occurred, except that the inception of the movement antedated Pleistocene time.

The four cross-sections, Figures 4, 5, 6, and 7 show the steep quaquaversal dips, and characteristic structure typical of the true salt dome. The sections are generalized. The transition from cap

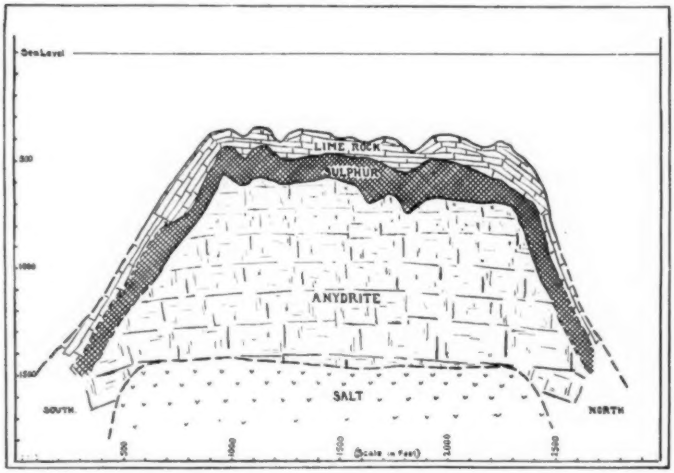

FIG. 4.—Sulphur salt dome, Louisiana, north to south section

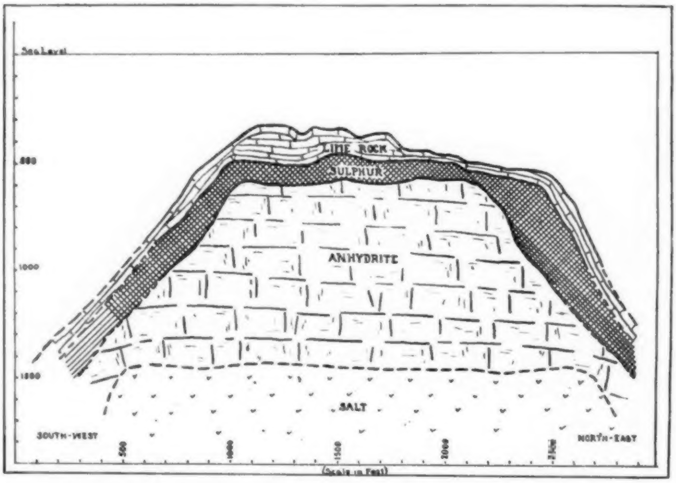

FIG. 5.—Sulphur salt dome, Louisiana, northeast to southwest section

rock to sulphur-bearing rock, and from the latter to gypsum and anhydrite, although abrupt in places, most commonly is gradual.

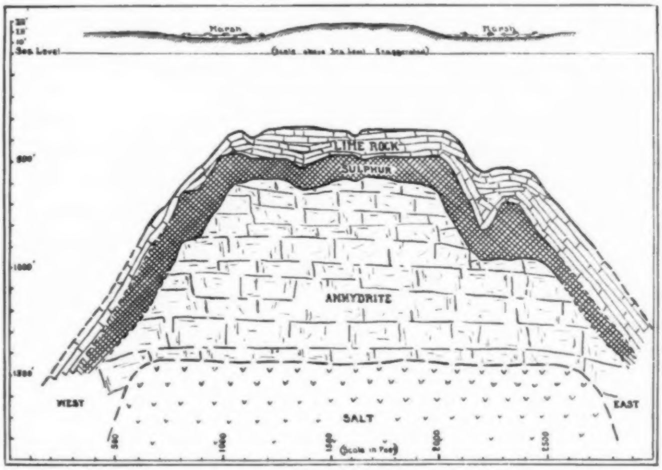

FIG. 6.—Sulphur salt dome, Louisiana, east to west section

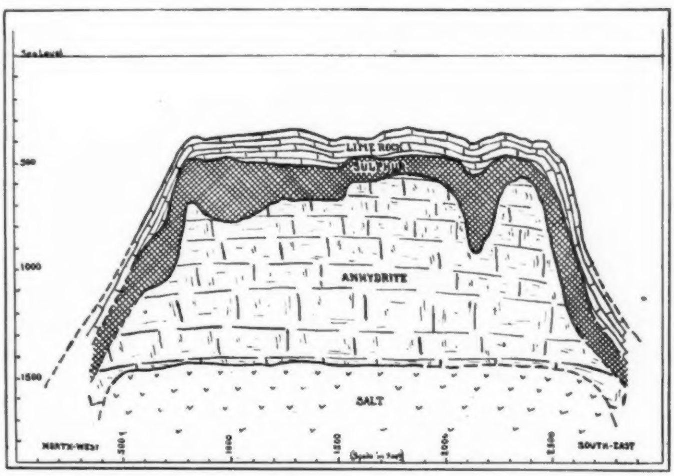

FIG. 7.—Sulphur salt dome, Louisiana, northwest to southeast section

The truncated top of the salt core is nearly level. Wells drilled 1,500 feet apart, with a difference in the elevation of the cap rock of several hundred feet, find the salt about the same depth, i.e., 1,460–65 feet below sea-level. No deep wells have been drilled on the sides close to the salt core, but the information obtained from shallow drilling indicates steep dips.

Unusual thickness of the cap-rock series marks this dome. The thickness of the cap rock superimposed upon the top of the salt core averages about 1,100 feet, of which some 900 feet is non-sulphur-bearing, practically pure anhydrite. The sulphur-bearing rock lies like a mantle, covering the top and sides of this anhydrite.

Different sections, perpendicular to the surface of the cap rock, whether on the flank or the top of the dome, display approximately the same thickness of sulphur-bearing formation. The gangue in the sulphur-bearing zone includes limestone, dolomitic limestone, anhydrite, and gypsum. There is a gradual vertical transition from limestone at the top of the zone through a mixture of limestone, calcite, gypsum, and anhydrite, to pure anhydrite at the base. The sulphur content is extremely variable; locally, the deposit ispure sulphur, but at the base of the zone it may contain as little as 1 per cent sulphur.

Over the sulphur-bearing rock is what the sulphur operator calls "cap rock," the nomenclature differing from that of the oil operator, who calls the entire rock series above the salt cap rock. The character of the cap rock at Sulphur Mine varies considerably, and consists in different places of the following: practically pure limestone impregnated with oil; limestone with calcite-filled cavities and veins, sandy limestone (one sample analyzed 48 per cent silica; the sand grains were cemented with calcium carbonate), and dolomitic limestone with magnesium content less than that of a true dolomite. All these may occur in the same vertical column of cap rock, with no uniformity or continuity, even as between two closely adjacent wells.

It is interesting to note that this upper cap rock contains little or no gypsum. The depcsiton of sulphur crystals is apparently largely confined to the zone which marks the transition from the non-

sulphur-bearing limestone cap to the non-sulphur-bearing anhydrite immediately overlying the salt. Unless the transition zone is present, no sulphur is encountered; the volume of the sulphur deposit varies directly with the thickness of the zone; and the richness of the sulphur deposit varies directly with predominance of carbonates over sulphates in the gangue. Other factors are important, of course; porosity, polysulphide waters under hydrostatic head; the presence of hydrocarbons, possibly some catalytic agent, all of these fit into one or more of the various theories for the origin of sulphur; but to the writer's knowledge, there does not exist in any dome a commercial deposit of sulphur where there is not also a considerable thickness of this transition zone. It therefore behooves the sulphur prospector to search out the thickly capped domes: where the entire cap-rock series is thin, the transition from the carbonate series to the sulphate series is abrupt, if indeed any carbonate is present at all, and consequently but little sulphur will be found.

OIL AND GAS

Wells drilled on the outer rim of the cap rock have passed through ledgelike projections, jutting out from the main body of rock. Between these projections lie sands and clays. Some oil occurs in these sands, but so far no effort to exploit the flank for oil has been made. In the early stages of the sulphur mining, two or three wells drilled into the top of the cap produced some heavy black oil. One well tapped the original gas pressure accompanying the oil, and flowed for a day or two at the rate of several hundred barrels per day. As soon as the gas pressure was relieved, the well started making sulphide water, and it was soon apparent that this well had about exhausted the cap-rock oil. This "gusher" gave rise to many erroneous ideas concerning the existence of a proved field, and kept the Sulphur Company busy denying wild rumors for several years thereafter.

SULPHUR

Various articles in the technical press of the country have described the Frasch process. Briefly, it provides for melting the

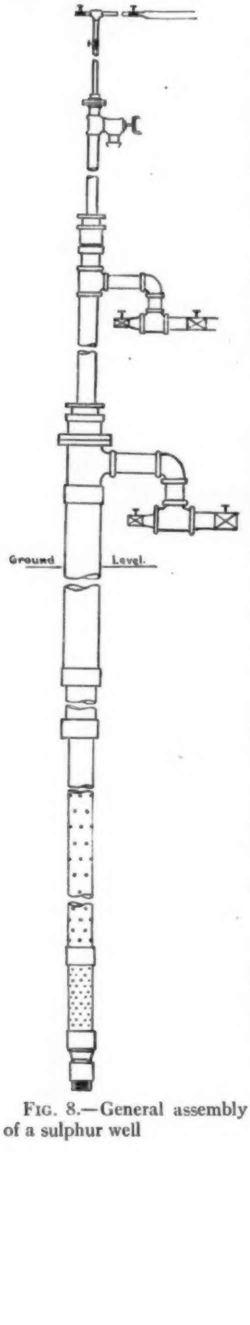

FIG. 8.—General assembly of a sulphur well

sulphur *in situ* by means of superheated water. The liquid sulphur is then brought to the surface by an air lift. The typical equipment, shown in Figure 8, can be modified to accommodate the special peculiarities of the well section, e.g., as to leanness, richness, or continuity of mineralization and presence of cavities. It permits egress of superheated water at any one of three different horizons in the sulphur-bearing zone, or all of them simultaneously, at the desire of the operator.

To conduct a mining operation at any major deposit requires an installation of from 15,000 to 30,000 boiler horse-power, and accessory equipment, consisting of heaters, pumps, pipe-lines, drilling rigs, receiving vats, railroad, oil and water storage, a water-supply of 10,000,000 gallons daily, etc., so that the initial expenditure is heavy. After the investment is made, sulphur recovery on a commercial basis is by no means certain; in fact, sulphur-mining is a much more hazardous business than producing oil. Once successfully on the way, however, it pays handsome dividends. From Sulphur Mine there have been produced about 9,000,000 tons of sulphur with a gross value of about $150,000,000.

Principally contributing to this large total is the higher price obtained for the product during the period the Union Sulphur Company had a natural monopoly on the American market. The present average per ton price is considerably lower.

Logs of two typical wells, (1) on top of the dome, and (2) on the side, follow:

1. RECORD OF TYPICAL WELL ON TOP OF DOME

	Depth in Feet
Sands, clays, and gravels	1–443
Lime rock	443–695
Limestone and sulphur	695–696
Porous, lost returns	696–710
Limestone, gypsum,* and sulphur, (core)	748–749
Limestone and fair sulphur, (core)	770
Limestone, gypsum, and sulphur, (core)	789–790
Limestone, gypsum, and sulphur, (core)	809–811
Limestone, gypsum, and little sulphur, (core)	829–830
Gypsum and little sulphur, (core)	849–851
Limestone, gypsum, and fair sulphur, (core)	869–870
Limestone, gypsum, and good sulphur, (core)	889–890
Limestone, gypsum, and sulphur, (core)	907–909
Gypsum and no sulphur, (core)	927–929
Total depth	939

2. RECORD OF TYPICAL WELL ON THE SIDE OF THE DOME

	Depth in Feet
Sands, clays, and gravel	540
Limestone	540– 660
Limestone, becoming porous	660
Sulphur crystals first appear	660
Limestone and sulphur	660– 666
Cavities	666– 667
Limestone, some sulphur	667– 676
Cavity	676– 680
Limestone, some sulphur	680– 800
Limestone and little sulphur, core	800– 802
Limestone and little sulphur, core	825– 827
Limestone and little sulphur, core	861– 862
Limestone and little sulphur, core	886– 888
Limestone and no sulphur, core	911– 912
Limestone and no sulphur, core	936– 937
Limestone and no sulphur, core	961– 962
Limestone and no sulphur, core	986– 988
Limestone, no sulphur, core	1,010–1,011
Limestone, no sulphur, core	1,030–1,031
Limestone, little sulphur, core	1,055–1,056
Limestone and little sulphur, core	1,080–1,081
Limestone and very little sulphur, core	1,105–1,106
Limestone and fair sulphur, core	1,130–1,131
Limestone and good sulphur, core	1,155–1,156
Cuttings, little limestone, extra good sulphur	1,156–1,181
All sulphur	1,166–1,168
Cuttings, limestone, gypsum, and good sulphur	1,168–1,192
Limestone, gypsum, and little sulphur, core	1,192–1,198
Limestone, gypsum, and good sulphur, core	1,216–1,217
Cavity	1,217–1,218
Limestone and gypsum and good sulphur, core	1,241–1,242
Lost returns at	1,254
Limestone, gypsum, and sulphur, core	1,265–1,266

* No effort was made in this log to differentiate gypsum from anhydrite.

	Depth in Feet
Limestone, gypsum, and good sulphur, core	1,292–1,293
Limestone, gypsum, and good sulphur, core	1,336–1,337
Cavity	1,349–1,350
Gypsum, limestone, and good sulphur, core	1,374–1,375
Limestone, gypsum, and good sulphur, core	1,400–1,402
Lost core at	1,425
Drilling changed	1,455
Gypsum, and no sulphur, core	1,459–1,461
Gypsum, and no sulphur, core	1,474
Salt	1,480
Depth of hole	1,610

ORIGIN OF THE SULPHUR

A great deal has been written both at home and abroad on the origin of the sulphur. A short bibliography is appended for the benefit of those who care to go into the more important chemical, geological, and physical hypotheses thus far brought forward.

Some of the factors upon the presence of which the existence of sulphur is conditioned are: (1) a relatively thick cap-rock series, with thick mass of carbonate overlying the gypsum-anhydrite; (2) a relatively thick transition series between the two, partaking of the character of both; (3) great porosity in the transition series; and (4) polysulphide waters circulating in the porous rock.

Regardless of how the cap-rock series in general is formed, sulphur is unquestionably a replacement material. The weight of the evidence indicates also that the actual precipitation of sulphur crystals occurs only from the sulphides, either as pure gases, as gases in solution, or as metallic sulphides in solution, principally of the calcium-magnesium group.

Analyses of the mine drainage water for two typical wells follow; the drainage water consists of a mixture of the "wild" waters naturally present in the rock and the fresh water pumped in during the mining operations.

1. ANALYSIS OF MINE WATER FROM SULPHUR DOME

Temperature	150–195° F.
Salt	50–1,000 grains per gal.
Sulphur in sulphides	50– 200 grains per gal.
Total solids	150–1,500 grains per gal.

2. ANALYSIS OF A TYPICAL WELL LOW IN SALT
(WELL No. 328)

Total solids	190.74
Iron and alumina F_2eO_3, Al_2O_3 (Fe 203, Al 203)	0.60
Silica (SiO_2)	3.60
Salt (NaCl)	41.40
Calcium sulphide ($CaSO_4$)	114.48
Calcium Carbonate ($CaCO_3$)	22.51
Sulphur in sulphides (S)	5.10
Ignition loss not sulphur	2.53
	190.22

Waters high in salt are low in sulphides, and vice versa; waters with a high salt content have also a high sulphate content; and as these two constituents increase, other salts diminish until almost all the total solids consist of calcium sulphate and sodium chloride. Magnesium commonly is present but only in small quantity.

OIL POSSIBILITIES

Two deep wells have been drilled on the west side of the dome, one in Section 19 by the Louisiana Exploration Co., and one in Section 30 by the Consolidated Sulphur and Oil Company. The locations of the wells, neither of which was productive, are shown in Figure 1. The logs of the wells are as follows:

LOG OF HUNTER No. 1—LOUISIANA EXPLORATION COMPANY*

CALCASIEU PARISH, LOUISIANA

SE. COR. SE. ¼ SE. ¼ OF SEC. 19, T. 9 S., R. 10 W., CALCASIEU PARISH, LOUISIANA

	Depth in Feet		Depth in Feet
Red clay	40	Cavey sand	490
Hard broken sand	47	Sand and gumbo	550
Clay and hard sand	77	Gumbo and gravel	620
Gumbo	107	Hard gumbo	628
Hard sand	108	Gravel	647
Quick sand, clay breaks	225	Packed sand	663
Gumbo	235	Hard sand and gravel	690
Stiff clay	250	Blue shale	729
Still clay	308	Fine gravel	750
Sand	365	Packed sand	756
Sand and gravel	413	Hard, broken sand	778

* Shells showed continually in cuttings from 2,987 to 3,390 feet, inclusive. Tested salt water. After pulling liner ran steel line 2,824 feet to bottom of hole.

	Depth in Feet
Loose gravel	785
Blue gumbo	809
Soft gray sand rock	812
Sand rock	815
Hard and soft sand	835
Tough gumbo	850
Shale and gumbo	876
Tough gumbo	880
Gumbo and shale	909
Hard and soft shale	930
Tough gumbo	938
Hard and soft shale	960
Tough gumbo	985
Sandy shale, shell, and lignite	1,033
Sandy shale	1,075
Hard shale	1,140
Sandy shale	1,166
Hard gumbo	1,197
Shale	1,230
Gumbo	1,250
Shale	1,280
Gravel	1,320
Gumbo	1,350
Sand	1,400
Gumbo	1,420
Gypsum	1,440
Gumbo	1,500
Hard sand and blue shale	1,521
Shale and bowlders	1,535
Gumbo	1,605
Shale and bowlders	1,665
Gypsum	1,685
Packed sand	1,691
Gypsum	1,693
Coarse sand and gravel	1,706
Coarse sand and gumbo breaks	1,785
Sand, gravel, and gumbo	1,800
Gumbo	1,820
Sand	1,850
Shale	1,900
Soft white rock	1,902
Gumbo	1,903
Sand and shell	1,987
Coarse sand and gravel	2,005
White sand and bowlders	2,010
Tough gumbo	2,020
Packed sand	2,027
Hard, broken rock and gravel in beds	2,035
Gravel and bowlders	2,055
Gumbo	2,065
Gravel	2,080
Gumbo	2,094
Tough gumbo and gravel	2,136
Tough gumbo and gravel	2,184
Gumbo	2,222
Gravel	2,287
Gumbo	2,307
Sand and gravel	2,408
Gumbo and bowlders	2,428
Gumbo	2,490
Gumbo	2,513
Gumbo	2,565
Sandy shale	2,640
Hard red shale	2,700
Shale	2,717
Loose shale	2,738
Hard shale	2,754
Loose shale	2,775
Hard gumbo	2,790
Chalk rock	2,794
Sand	2,840
Sand	2,882
Packed sand	2,840
Red shale	2,860
Chalk rock	2,864
Red shale	2,880
Gray sandy shale	2,911
Chalk rock	2,916
Hard shale	2,955
Shale	2,987
Gumbo	3,007
Gumbo	3,037
Gumbo	3,057
Gumbo and bowlders	3,082
Pyrites of iron	3,100
Pink shale	3,124
Pink shale	3,140
Pink shale	3,160
Bowlders and shale	3,180
Pink gumbo	3,198
Rock and pyrites	3,220

	Depth in Feet		Depth in Feet
Rock and pyrites	3,240	Gumbo	3,390
Gumbo and shale	3,270	Gumbo, red and blue, very tough, pyrites and some lime in cuttings	3,433
Gumbo and shale	3,285	Hard drilling, lime, sand, shale, lignite and pyrites in cuttings	3,468
Rock and gumbo	3,300	Pink shale, lime streaks, and a little sand	3,532
Gray shale	3,310	Lime rock	3,545
Gumbo and pyrites	3,321	Gumbo	3,552
Gumbo and shale	3,331	Lime rock	3,557
Gumbo and rock	3,341		
Gumbo and bowlders	3,350		
Bowlders and gray shale	3,360		
Gray shale and shell	3,380		

LOG OF WELL OF CONSOLIDATED SULPHUR AND OIL COMPANY*

Sec. 30, T. 9 S., R. 10 W., Calcasieu Parish, Louisiana

	Depth in Feet		Depth in Feet
Gumbo and sand	1–534	Gumbo	1,652
Blue gumbo	554	Gypsum	1,660
Blue shale	575	Shale	1,679
Shale	959	Gumbo	1,710
Sand	765	Green shale	1,730
Gumbo	811	Gumbo	1,740
Mud and shell	877	Shale	1,750
Shale and mud streaks	1,120	Gumbo	1,770
Gumbo and hard shale	1,180	Shale and sand	1,790
Very tough gumbo	1,188	Gumbo and bowlders	1,800
Gumbo and rotten lime	1,195	Rock	1,804
Sand and shale	1,250	Shale, sand, and some gas	1,844
Shale	1,270	Gypsum and bowlders	1,882
Pink gumbo	1,290	Gumbo	1,920
Green shale	1,310	Shale and sand	1,947
Shale and gumbo	1,352	Gumbo	1,969
Fine white sand	1,375	Shale and sand	1,990
Blue gumbo	1,415	Pink gumbo	2,012
Shale	1,435	Hard shale	2,034
Blue gumbo	1,450	Gumbo and pink shale	2,055
Shale	1,470	Shale and pyrites	2,078
Gumbo	1,475	Shale and bowlders	2,099
Shale and pyrites	1,524	Gumbo	2,121
Hard shale and pyrites	1,540	Shale and pyrites	2,130
Gumbo and hard shale	1,600	Gumbo	2,150
Shale and sand	1,620	Shale, pyrites, bowlders, gas	2,182
Hard shale, sand gas	1,640	Gumbo and gypsum	2,237

* Set screen on December 18, 1915, bottom of screen 2,876 set in gumbo. Set 6-inch 2,847 in gumbo pay 2,853–59. Good pay, 2,859–66. Breaks of pay in shale, brown and red, into rock 2 feet and sand to 2,876. Set 1,193 feet of 8-inch pipe. Pay rock, 2,853–2,861.

	Depth in Feet
Soft sand	2,265
Gumbo	2,286
Gumbo, red streaks	2,320
Sand	2,341
Gumbo and gypsum	2,355
Shale and sand	2,381
Rock	2,383
Sand and shell	2,400
Blue gumbo	2,420
Green shale	2,435
Gumbo	2,450
Shale and sand	2,465
Gumbo	2,490
Green shale	2,505
Gumbo and red shale	2,512
Red sand	2,515
Red gumbo	2,534
Shale and sand	2,588
Red gumbo streaks	2,620
Gypsum rock	2,625
Gypsum and gumbo	2,650
Red gumbo and gypsum	2,681
Red and blue shale	2,715
Red and blue gumbo	2,720
Red and blue shale	2,800
Tough and hard gumbo	2,810
Rock	2,811
Sand	2,812
Gumbo	2,815
Pink shale	2,833
Pink shale	2,835
Red and blue gumbo	2,853
Oil show, rotten rock	2,859
Oil	2,853–66
Oil show, rotten rock	2,866
Gumbo	2,868
Gypsum, brown shale, and oil show	2,870
Hard places, oil show, brown shale	2,884
Rock and oil show	2,886
Hard sand and oil show	2,892
Gumbo	2,895
Rock	2,897
Gumbo and shale	2,932
Tough gumbo and soft places of red shale	2,942
Good gumbo	2,958
Shale	2,970
Shale mixed color	2,984
Hard dry shale	2,994
Gumbo	3,105
Hard shale	3,128
Gumbo and shale	3,140
Shale	2,955
Soft shale	3,190
Hard shale	3,198
Gumbo and gypsum streaks	3,209
Gas rock rotten gypsum	3,212
Mud and seams of sand and pyrites	3,290
Gas rock	3,294
Gumbo and pyrites	3,343
Tough gumbo and gypsum	3,351
Muck, shells, and muddy shale	3,360
Gumbo, shale, and pyrites	3,370
Gumbo and seams of shells and pyrites	3,379
Shale, shell, and gas showing	3,392
Gumbo and gypsum	3,408
Blue shale and shells	3,430
Shale and pink gumbo	3,474
Rock gypsum, gas, and some oil	3,477
Shell, pyrites, mixed color	3,481
Blue and pink gumbo	3,490
Gypsum rock	3,492
Gumbo and gypsum	3,502
Gumbo	3,531
Gumbo, shale, and sand seams	3,537
Gumbo	3,574
Gumbo and shale break	3,584
Gumbo and hard shale seams	3,593
Hard shale	3,623
Gumbo	3,633
Gumbo and gypsum, hard places	3,639
Gypsum rock, soft places	3,642
Gypsum rock, upper 2 feet very hard	3,648
Hard shale and sand, some gas	3,679
Tough gumbo	3,697
Rock, gas showing	3,705
Shale	3,736
Gumbo and gypsum rock	3,780

	Depth in Feet
Shale streaks blue and brown sand	3,829
Very tough gumbo	3,852
Hard shale	3,884
Gypsum and gumbo	3,910
Gypsum rock, hard and smooth, all seams gas	3,931
Gypsum and gumbo, blue very hard	3,952
Gypsum rock, hard and seams show oil and gas	3,965
Hard sand oil and gas, stop in rock	3,984
Hard rock	3,995
Crystallized sand, hard places	4,016
Hard red shale, pyrites sand streak	4,016
Gypsum and gumbo	4,030
Sand and gas (show fine)	4,042
Gypsum and gumbo, red blue tough	4,065
Hard sand shale, blue and brown oil show	4,075
Gypsum and hard sand	4,102
Seams of very tough gumbo	4,104
Crystallized sand and pyrites	4,108
Crystallized sand and pyrites	4,112
Gypsum	4,130
Rock, fine, showing oil very light	4,137

One unusual advantage presented by this dome is the fact that one owner has title to all fee completely surrounding it. There would be no difficulty in testing all sides of the dome, under a single lease.

Oil seems to be most plentiful in shallow sands along the north and east sides of the dome, and while no close-in deep drilling has been done, the information developed by shallow holes indicates a slightly more gradual dip on the northeast slope.

ACKNOWLEDGMENTS

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THE EDGERLY OIL FIELD, LOUISIANA

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ABSTRACT

The Edgerly oil field is located in the southwestern part of Louisiana in a topographically featureless part of the Gulf Coastal plain. Exploration for oil was based on gas seepages, and though a total production of more than 55,000 barrels of oil per acre has been obtained from the field, there is no indication of a salt dome other than the local steep dips away from the field. No salt, gypsum, or cap rock has been encountered in any well. There are four main producing sands, at average depths, respectively, of 2,700, 2,900, 3,000, and 3,100 feet.

SITUATION

The Edgerly oil field is located in Calcasieu Parish, Louisiana, in Sec. 28 and 29, T. 9 S. R. 11 W. (Fig. 1). The field is $\frac{1}{2}$ mile north of the town of Edgerly, on the main line of the Southern Pacific Railroad approximately midway between Beaumont, Texas, and Lake Charles, Louisiana.

HISTORY

Gas escapes and so-called "paraffin dirt" were noted near Edgerly as early as 1906. On the Lillard property there were several gas seeps which boiled constantly when the area was under water, and which when dry could be detected by the strong odor of hydrogen sulphide gas. The seeps cover a circular area 10–15 feet in diameter, in crossing which one has the feeling of walking upon very stiff gelatine or rubber. There were also considerable showings of live gas in the marsh near the northeast corner of Section 28.

These indications were first brought to the attention of the Higgins Oil Company by Lee Hager in 1906. This company undertook exploration of the area, locating their initial test in the center of Section 28. Drilling was begun September 10, 1907, and the well was carried to 1,820 feet, where salt water was encountered. It was then decided to perforate the well at 1560 feet, and, on doing so, the well blew out making considerable dry gas and sand. Although several oil showings were reported while drilling, the well was abandoned after the blow-out. A second test was made about 300 feet north of No. 1. This well was drilled into salt water and abandoned at 2,025 feet. Well No. 3 was drilled 600 feet south of No. 1 and abandoned at 1,980 feet without finding anything of importance. In the early part of 1910, Hooks *et al.* drilled a well about 250 feet east of the Higgins Oil Company's No. 1, and at a depth of 1,200 feet, a showing of 16°

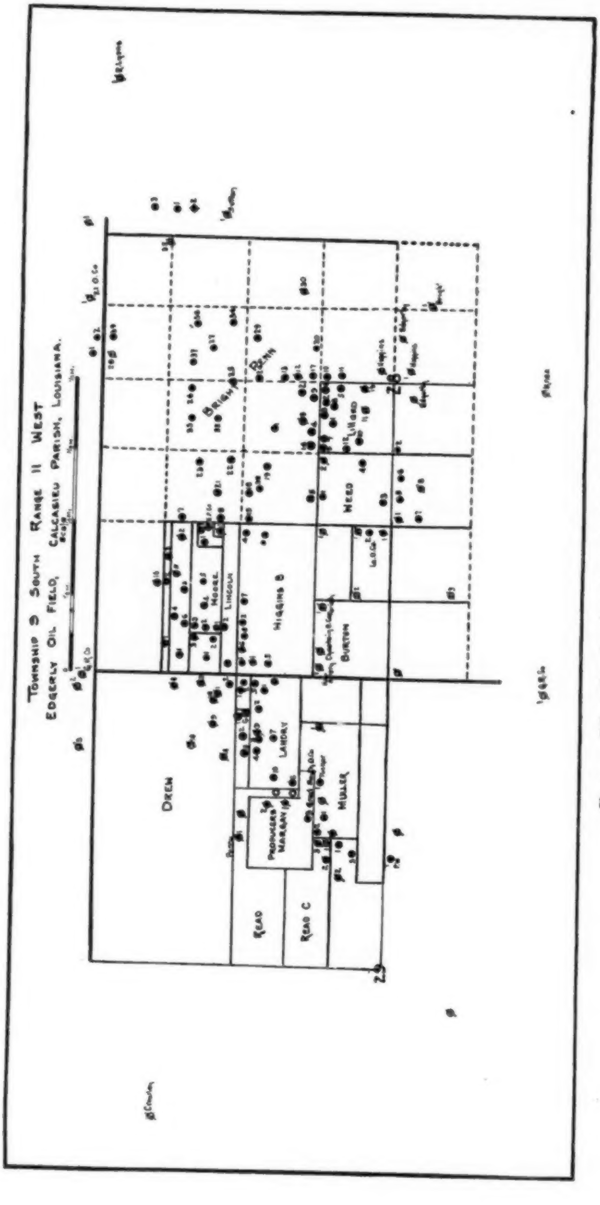

FIG. 1.—Map showing location of Edgerly oil field

Baumé oil was encountered. However, the well failed to produce oil and after being drilled to 2,477 feet was abandoned. Another well was located 200 feet east of No. 1 Hooks and was abandoned at 1,600 feet without any show of oil or gas. Later, two other wells were drilled, one by the Twenty-one Oil Company, being located in the southeast corner of the southeast quarter of the southwest quarter of Section 21, and the other by the Bright Oil Company (Jim Sutton *et al.*) on the Bright property. These wells were abandoned at 2,360 and 2,500 feet, respectively, without encountering anything of interest.

The first producing well was drilled in the southeast corner of the northeast quarter of the southeast quarter of Section 28, by the Bright Oil Co. At 1,300 feet the first test was made, resulting in a 2,000–barrel salt-water flow with five barrels of oil. The well was deepened to 1,500 feet, one joint of 2½-inch strainer set, and the well flowed 250 barrels of 17.5 Baumé oil. The discovery resulted in the acquisition of the Bright Oil Company's properties by the Gulf Refining Company of Lousiana on March 29, 1912.

GEOLOGY

There is no topographic relief at Edgerly; the surface slopes gently to the south in conformity with the general slope of the Texas-Louisiana Gulf Coast area. Although a number of deep tests have been drilled, none of them have encountered cap rock, gypsum, or dolomite; thus this field is to be placed in the same class with Goose Creek, Orange, and Welsh, at none of which has any direct evidence of a salt dome been revealed.

The production occupies an oval area approximately 5,000 feet east and west by 1,400 feet north and south. Edge wells reveal steep dips to the north, south, and west, and are characterized by the presence of mottled red and blue shales with thick beds of coarse sands, typical of edge wells in other fields of this type. The few fossils obtained from the Edgerly field have been determined as Pliocene, and it is doubtful if any of the production is obtained from older beds.

The principal producing horizons are the 2,700-, 2,900-, and 3,100-foot sands as illustrated in Figure 2. In addition to these horizons, an area of ten or fifteen acres in the southeastern portion of the field produces from a depth of 2,300 feet.

Correlation is made more certain by water analysis. The writer[1] has previously discussed the application of chemical analysis of waters to correlation. On the basis of the data presented in that discussion, the salt concentration of the 2,300-foot horizon may be

[1] Chemical Relation of Salt Dome Waters. This Bulletin, Vol. 8 (1925), pp. 38–41.

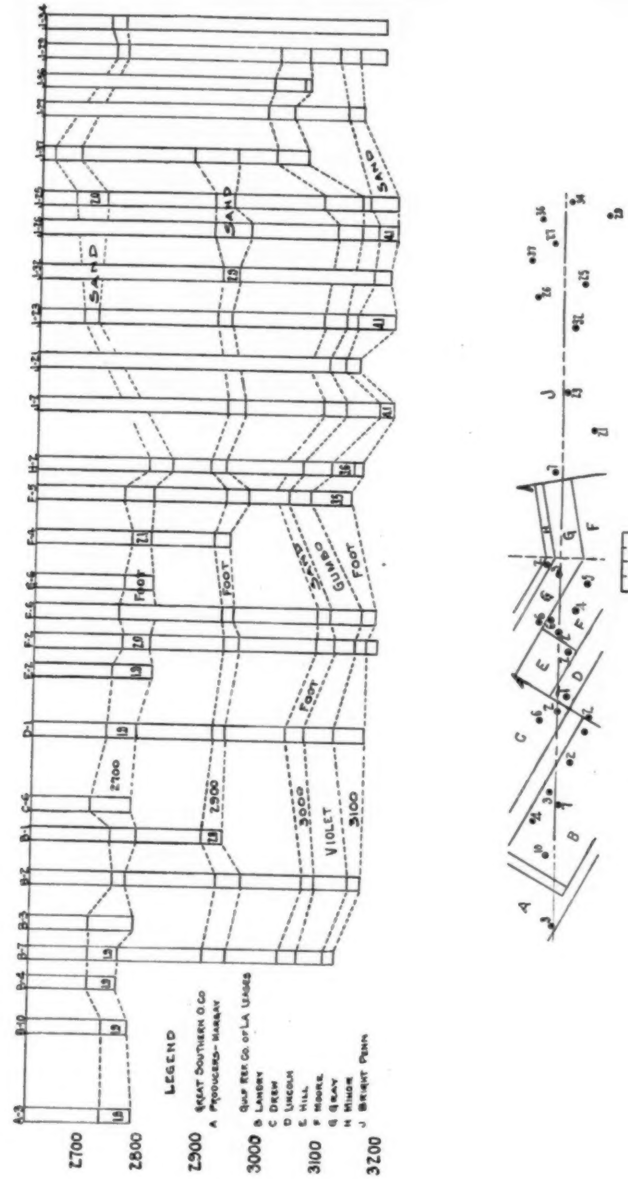

FIG. 2.—Section across field, Edgerly, Louisiana, showing principal producing horizons

interpreted as indicating a vertical uplift from 300 to 500 feet greater than in the field proper (Fig. 3). The 2,700-foot sand is very persistent in areal extent, and since it is composed almost entirely of fine breccia, is easily identified. This sand assumes a true dome structure with a closure of about 60 feet, the apex being near the southeast corner of the Drew lease of the Gulf Refining Company of Louisiana. The greatest production occurs along the crest of the fold, the major

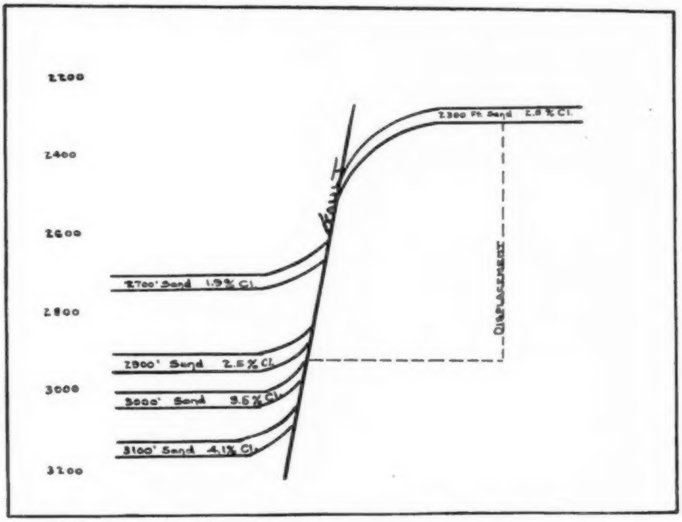

FIG. 3.—Diagram of faulted area

axis of which trends in a northeast-southwest direction. The 3,000- and 3,100-foot sands are interbedded with a violet-colored gumbo which serves as a key bed in the correlation of the strata. Good wells have been completed in these sands over most of the area of the field, showing that these sands are more persistent than any of the other producing horizons.

DEEP EXPLORATORY DRILLING

None of the deep tests that have been drilled at Edgerly has revealed any deeper producing horizon than the 3,100-foot sand.

In the center of the field the Gulf Refining Company of Louisiana drilled their Bright-Penn No. 38 to 5, 425 feet, without finding deeper production. On the northeast boundary line of the field, Bright-Penn No. 28 of the same company was carried to 3,280 feet. A mile farther east, the Richard Lyons No. 1 was abandoned at 3,918 feet. On the northwest side of the field, Drew No. 10 was drilled to 4,275 feet. To the southeast on the Maurice J. Muller lease, the Miller Oil Company drilled their No. 2 to 3,910 feet without results. To the south the Gulf Refining Company of Louisiana drilled No. 1 Higgins "C" to 3,737 feet, No. 2 Wilson to 3,668 feet, and No. 8 Higgins "A" to 3,720 feet. On the west, Bright-Penn No. 30 was drilled to 3,887 feet. With deep tests practically surrounding the field, there is little chance for an extension of the present productive area.

CHARACTER OF OIL

The oil produced from Edgerly is typical Gulf Coast crude, ranging in gravity from 19°-to 22.5° Baumé. None of the light gravity or freak oil encountered in other salt-dome fields has been developed. The refined product makes an excellent lubricating oil. The analysis of an Edgerly crude oil is given below:

ANALYSIS OF AN EDGERLY CRUDE OIL

Gravity: 18.9° Bé. Sulphur: 0.31
Color: almost black Boiling-point: 420° F.

Per Cent	Degrees F	Gravity
10	521	30.6
20	568	26.5
30	612	24.0
40	638	21.9
50	662	21.5
60	660	22.6
70	644	24.1
80	620	26.1
90	688	24.3

PRODUCTION

The production curve (Fig. 4), shows a gradual decline from a peak of 1,688,862 barrels in 1915. The decline has been very regular and practically free of periodic peaks which are so common

to most of the salt-dome fields. The total production for the Edgerly field at the close of 1923 was 6,880,000 barrels, which gives a total of 55,000 barrels per acre, but with water encroaching and practically

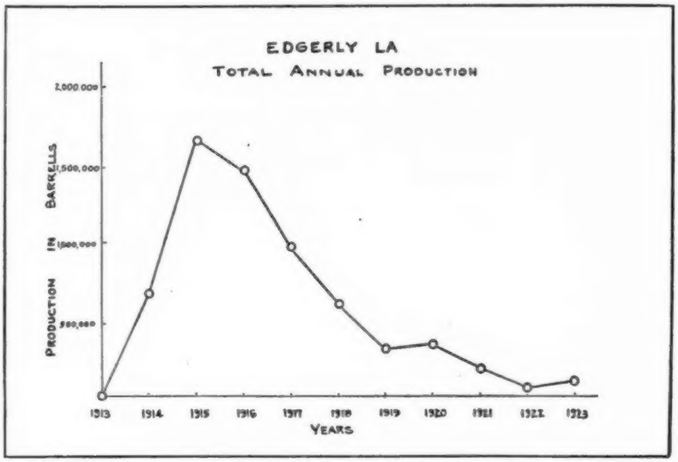

FIG. 4.—Production curve

all of the area within the limits of production drilled, it is doubtful if it will ever exceed 70,000 barrels per acre. The daily average production of January, 1924, was distributed as follows:

TABLE I

Company	No. Wells	Production in Barrels
Gulf Refining Co. of La.	12	267
Great S. O. Co.	1	15
Muller *et al*	1	15
Emerson & Sutton	1	10
G. W. Gray	1	12
A. L. Gibson	5	93
Lake Charles P. Co.	1	14
Total	22	426

The Gulf Refining Company's E. J. Fairchild No. 1, completed April 23, 1914, at a depth of 3,170 feet with an initial production of of 6,000 barrels, is the banner well of the field. This well produced

until 1918, making a total of 226,158 barrels of oil. There have been more than a half-dozen wells which have produced over 100,000 barrels of oil each.

DRILLING METHODS

On account of the comparatively soft nature of the strata at Edgerly the rotary method of drilling is exclusively used. The cost of drilling and equipping wells ranges from \$7,000 to \$10,000 for 2,300-foot wells and \$20,000 to \$25,000 for wells completed in the 3,100-foot sand. The average well is drilled in from thirty to forty-five days.

PRODUCING PRACTICE

All wells are pumped with the standard rig using steam power. A considerable amount of water is producing with the oil, necessitating the treating of the emulsion, which is done almost entirely by steam plants located upon the various leases.

FUTURE POSSIBILITIES

In view of the comparatively small productive area at Edgerly and the apparent absence of deeper producing horizons, it is not probable that drilling activity will ever resume an upward trend. Stimulation of the market may promote further drilling and the re-working of old wells, but water is encroaching in all of the producing sands and the future will depend on the ability of the producers to extract the remaining oil by careful drilling and skimming methods.

THE DAMON MOUND OIL FIELD, TEXAS

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ABSTRACT

Damon Mound is a conspicuous rounded elevation in northwestern Brazoria County, Texas, 38 miles southwest of Houston. It is oval in shape, covers an area of 1,670 acres and rises 83 feet above the surrounding prairie. This elevation is the result of an intrusive salt plug which has raised the surface above its normal position.

The salt plug is composed of almost pure rock salt and is capped by deposits of gypsum, anhydrite, and limestone. Formations surrounding the salt plug are inclined at angles of about 45° away from the salt plug. Mineralized water and gas seepage in shallow water wells, sour dirt, sulphur, and lime rock on the surface are indications of the salt dome.

Two hundred ninety-one wells were drilled prior to the year 1924, 85 producing oil, 154 being dry, and the remainder being classed as sulphur tests. Total production for this period amounts to 5,008,870 bbls., all of which was obtained from an area of 280 acres. There are two producing areas, one on the northeastern side, the other on the southwestern side of the dome. The major portion of oil was obtained from the southwestern side. Production per acre averages 19,265 bbls. Average production of producing wells is 58,927 bbls., and the average depth 2,416 feet. The oil is of asphaltic base with gravities averaging about 22.5° B. Production is obtained around the sides of the dome in sands and limes of Oligocene age.

INTRODUCTION

Damon Mound is located on the Abram Darst survey, in northwestern Brazoria County, Texas, near the Fort Bend County line. It is 38 miles southwest of Houston, 9 miles south of Big Creek, and 10 miles northwest of the West Columbia oil field. A branch of the G. H. & S. A. Railroad extends from Rosenberg to Damon City on the mound. Overland travel by automobile from Houston is satisfactory during dry weather, but roads occasionally become impassable in rainy seasons.

HISTORY

Damon Mound was a famous camp site and stronghold of the Karanawa Indians. They recognized the advantages of this natural elevation and established a settlement on its upper portions. Numerous remains such as arrowheads, pottery, stone implements, and burial grounds are evidence of this early settlement. On the western side of the mound the Indians found a bluish-black substance within and about a crater-like formation. It was unlike the surrounding soil, possessed a sour, acid taste, and was always moist. By drinking water

which collected in this substance, the Indians discovered that it possessed curative properties. The renown of this "medicine" spread far and wide, attracting others from districts as far as the present state of Oklahoma. The substance referred to is commonly known as "sour dirt," and is an indication of salt-dome formation. It is now being developed and sold as a medicine.

In 1831, Samuel Damon, Sr., located and established a blacksmith-shop at Damon Mound. While in search for building material, he discovered an outcrop of limestone on the eastern slope of the hill. A quarry was established, and for many years this material was used for building purposes, some of it being shipped by rail to Houston. Water invaded the quarry, and it has been idle for many years. The stone is described as a warty, cavernous limestone, and is probably a portion of the cap rock which has reached the surface.

During the growth and development of the community now known as Damon City, numerous shallow wells were sunk in search of domestic water. Much of this water is mineralized, and no two wells appear to contain water of the same composition. Water in a 40-foot well near the hotel is saline, while wells on the southwestern portion of the dome are generally fresh. A 206-foot well drilled by Mr. Mulcahy, south of the central part of the dome, produces strongly sulphuretted water containing little or no salt. A small amount of inflammable gas rises within a few wells on the mound, but the majority contain no gas.

Crystals of pure sulphur are exposed along the sides of gulleys on the northern portion of the hill. They occur in isolated patches or spots, some of the crystals being an inch or more in length. Several such deposits were found on the Wallace, Mays, and Wisdom properties. The sulphur is of secondary origin and has been deposited within crevices and porous formations by ascending vapors or solutions.

Sour dirt occurs on the western side of the hill within a 6-acre tract owned by the Vitalitas Company. The deposit is irregular in shape and largely confined to an area of about 1 acre. The material is bluish black in color, but weathers to a pale yellowish brown on exposure. It is largely composed of siliceous material containing quantities of iron pyrite and marcasite. The whole is impregnated with soluble sulphates and chlorides of iron, aluminum, magnesium, sodium, and calcium, together with a small amount of free sulphuric acid. The deposit is of secondary origin and was probably formed by the reaction of escaping sulphurous gases with water and material of adjacent formations. It is reported that tests of the sour dirt indicate a small amount of radioactive material; however, a sample submitted by the writer to the Radium Chemical Company of Pittsburgh contained no radioactive elements. A chemical analysis of the raw material, made by Dr. E. H. S. Bailey, of the University of Kansas, shows the composition given in Table I. Dr. P. S. Tilson, of the Houston Laboratories, gives an analysis based on 100 per cent of the water-soluble material, as shown in Table II.

INDICATIONS OF SALT-DOME STRUCTURE

Indications of salt-dome structure are numerous and easy to identify at Damon Mound. The most impressive is the high, rounded elevation, which is plainly visible for a distance of 5 or 6 miles. The occurrence of inflammable gas and highly mineralized water in shallow wells, sour dirt, crystallized sulphur, and lime rock on the surface are all regarded as companions of salt-dome formation. Many of these indications were recognized and believed to be associates of salt and oil deposits prior to the discovery of oil in Gulf Coast territory; however, little was known about the nature of salt-dome structure, and it required a well such as the famous Lucas gusher of Spindletop to direct the attention of operators to Damon Mound.

TABLE I

	Per Cent
Silica	59.33
Ferric oxide	22.40
Sulphuric anhydrid	3.07
Sulphur	16.13
Water	1.85

TABLE II

	Per Cent
Iron sulphate, $FeSO_4$—$7H_2O$	40.003
Aluminum sulphate,—Al_2—$3(4SO_4)$—$16H_2O$	37.856
Sodium-alum, $2(SO_2)$—$12(H_2O)$	7.246
Calcium chloride, $2(CaCl_2)$—$6H_2O$	.736
Calcium sulphate, $CaSO_4$—$7H_2O$	1.985
Magnesium chloride, $MgCl_2$—$6H_2O$	1.651
Magnesium sulphate, $MgSO_4$—$7H_2O$	3.140
Sodium chloride, NaCl	2.327
Sodium sulphate, $4(Na_2O)$—$10H_2O$	5.056

DEVELOPMENT

Mr. J. M. Guffey, prominent in the early development of salt-dome oil fields, was the first to acquire leases at Damon Mound. His initial test, known as the Herndon well, is located on Mulcahy Avenue, Block 3, of the Damon High School addition. The well was completed late in the year 1901 at a depth of 1,160 feet. Rock salt was entered at 587 feet and continued to the bottom. No showings of oil or gas are reported, but this test clearly demonstrated the presence of a salt dome. Two additional wells were drilled by Mr. Guffey at the base of the dome, one on the northern side, the other on the northwestern side. No showings of oil or gas are reported from either well, and it is said that the drills penetrated a series of unconsolidated sands, shales, and clays. A total of five wells were drilled in four years without obtaining a favorable show of oil or gas. Owing to the activity of other fields, Damon Mound was neglected from 1905 to 1914.

Early in the year 1915, Mr. H. T. Staiti and associates organized the Texas Exploration Company, acquiring leases and mineral rights covering a greater portion of the mound. Their initial test, Wisdom No. 1, was located by Mr. E. F. Simms on Block 6 of the Wisdom subdivision, near the western base of the hill. A depth of 1,953 feet was reached after passing through 940 feet of rock salt. During the progress of drilling, a particularly favorable showing of oil and gas appeared in a sandy formation at 650 feet. Before abandoning the location, it was decided to test this horizon. The well came in November 15, 1915, and ran wild for a time, making about 5,000,000 cubic feet of gas and 100 barrels of oil per day. The countryside was covered with oil spray carried by a strong wind for a distance of more than 2,500 feet. After some difficulty the flow was controlled and, owing to insufficient storage, was shut in. It later sanded, and the hole was finally junked in an effort to revive production. The oil has a gravity of 35° Baumé, several hundred barrels of which were collected and used for fuel in drilling other wells. This is the first well to produce oil at Damon Mound, and although not a commercial success, it served to demonstrate the presence of oil and attracted the attention of other operators to this field.

Fifteen wells were drilled in 1915, all of which are reported as failures. Most of these tests are located on top of the hill, the majority being abandoned in salt or gypsum at shallow depths. While drilling on the Wallace and Mays tracts, crystals of sulphur were noted coming up with the returns, and during the following year prospective work was started in an attempt to outline and determine the thickness of these deposits.

The year 1917 was a period of intense activity, seventy-seven wells being drilled, of which ten produced oil, forty-three were dry, and the remainder completed as sulphur tests. Production increased to 69,000 barrels during the month of April, declined rapidly, and again increased to 74,700 barrels in August. The major portion of this increase is due to the completion of two wells, Bryan No. 1 and Bryan No. 3, by the Texas Exploration Company.

Bryan No. 3 is not only the first successful well, but the best well ever obtained at Damon Mound; it came in April 5, 1917, making dry gas, and ran wild for twelve days. Oil then appeared and increased in quantity to about 400 barrels per day, when it sanded. The well was later cleaned and started flowing at the rate of 7,500 barrels per day. Thirty-nine feet of hard, porous, calcareous rock, showing considerable oil and gas, were penetrated from 1,410 to 1,449 feet. No screen was set in this well, and top water was excluded by setting $4\frac{1}{2}$-inch pipe on top of the rock. The oil has a gravity of 24° Baumé with an initial temperature of 90° F.

No. 1 T. H. Bryan was completed June 30, 1917. This well, like Bryan No. 3, came in making dry gas and about 400 barrels of oil. Production, however, increased rapidly, and within a short time was flowing pipe-line oil at the rate of 3,500 barrels per day. Sixty-one feet of 3-inch screen was set at 3,473 feet in sand and shale containing a rich oil show. The oil has a gravity of 20° Baumé

and initial temperature of 90° F. Three additional producers completed by the Texas Exploration Company within the year, together with five completions by other operators, gave an additional 2,600 barrels initial production, all of which came from depths of approximately 1,500 feet.

During the latter part of 1917 the Texas Exploration Company transferred all of their holdings, excepting sulphur rights, to the Sinclair Oil and Gas Company. The Sinclair organization assumed immediate control and started an active campaign for the development of oil and gas deposits. The Texas Exploration Company remained in the field finishing wells already started and continuing prospective work for sulphur deposits.

Eighty-five wells were completed during the years 1918–19, of which twenty produced oil, fifty-one were dry, and the remainder drilled as sulphur tests. The Texas Exploration Company's No. 1 Radmohr is the best well of this period. It was completed as a 350-barrel producer at 2,527 feet, but made large quantities of water with the oil. The twenty producing wells gave a combined initial production of 2,269 barrels, most of which came from depths around 1,500 feet. Production declined rapidly, then remained fairly constant at an average of 22,500 barrels per month from January 1, 1918, to May 1, 1920.

The year 1920 is perhaps the most important in the history of Damon Mound development. Nineteen wells were completed, ten of which produced oil, adding a total of 15,560 barrels initial daily production to the field. Production increased rapidly to a maximum of 150,375 barrels during the month of December, which is the greatest production recorded in the history of the field. Three wells of the gusher type were completed by the Sinclair Oil and Gas Company, Bryan Nos. 15 and 16 and Masterson No. 10. The Humble Oil and Refining Company also secured a good well in their No. 2 Gallaher. All of these wells are located on the southwestern flank of the dome.

Bryan No. 15 came in during the latter part of April with an initial flow of 2,500 barrels per day. After cleaning itself, the flow increased to 4,000 barrels, making pipe-line oil containing 0.1 per cent water and basic sediment. The gravity of the oil was 23° Baumé with an initial temperature of 80° F. One hundred and forty-two feet of 4-inch screen was set on bottom at 3,103 feet, including a series of sands and shales with some gumbo and bowlders. Shows of oil were recorded at intervals, with 15 feet of very rich sand at 3,088 to 3,103 feet.

The Humble Oil and Refining Company obtained a 1,000-barrel well in No. 2 Gallaher at 3,213 feet. Three joints of 80-mesh screen was set on bottom. including 90 feet of sandy shale containing an occasional oily horizon. The well came in September 16, producing 23° gravity oil containing 0.2 per cent basic sediment and water.

The Sinclair Oil and Gas Company's No. 16 Bryan is generally recognized as the second largest well of the field. It was completed September 24, with an initial flow estimated at 5,000 to 6,000 barrels per day. The oil has a gravity of 21° Baumé with initial temperature of 94° F. and contains 0.05 per cent water

and basic sediment. One hundred and thirty-six feet of 10-gauge, 4-inch strainer was set on bottom at 2,774 feet. The formations included in this setting are largely composed of alternating sands, shales, and gumbo, containing an occasional show of oil and gas. A hard, sandy rock at 2,693 to 2,712 feet is the principal producing horizon.

Masterson No. 10 was drilled to 3,256 feet and completed December 3, with an initial flow of 5,000 barrels per day. Production is obtained from sandy horizons containing some shale, at 3,133 to 3,152 feet and at 3,185 to 3,205 feet. The oil is of 21° gravity with an initial temperature of 90° F.

Eight producing wells and thirteen dry holes were drilled during the year 1921, the largest well of this group being the Sinclair Oil and Gas Company's No. 18 Bryan, which was completed as a 1,200-barrel producer at 3,213 feet. A very interesting test, known as R Damon No. 1, was made by the Hyde Production Company on the southern edge of the field. While drilling at a depth of 2,670 feet, the well blew out and ran wild from October 2 to 6, producing large quantities of gas and salt water. The derrick and toolhouse were wrecked before the flow sanded. Drilling operations were resumed and the well side-tracked to 3,255 feet in heaving shale. It was then decided to shoot the well and test a sandy horizon showing oil and gas at 3,170 feet. This shot resulted in a second blowout more severe than the first. The derrick and immediate equipment were lost, and the blow lasted for eleven days, throwing out large quantities of gas, salt water, sand, and shale. The well sanded up December 31, 1921, but was completely ruined.

An increase in activity during the year 1922 failed to increase materially the production over that of the previous period, and although a high percentage of wells obtained production, yet it was very evident that the heavy drain upon the producing horizon had decreased the pressure to a point where gusher wells could no longer be expected from further drilling in the old field. An attempt to find new sources of supply by deeper drilling resulted in the majority of wells being abandoned in heaving shale. Other portions of the field to the east and south were tested without obtaining any producer of importance.

During the summer of 1922 the Union Sulphur Company entered the field primarily in search of new sulphur deposits. An option or agreement with the Texas Exploration Company permitted the sulphur company to proceed with a series of test wells. Their first well, located on Block No. 11 of the Wisdom subdivision, was completed October 8, at a depth of 347 feet.

The operations of 1923 were largely a continuation of prospective work in an effort to locate a new pool on the eastern and southern sides of the field. All wells on the southern side of the dome entered heaving shale, and such oil sands as were found did not yield more than 10 to 15 barrels of initial production when tested. Those on the eastern side encountered exceedingly steep dips, and although slightly better results were obtained, the wells were of short life and did not justify the expenditure. The Union Sulphur Company completed a series

of nine wells, established a battery of steam boilers, and made an experimental steam test in an effort to determine the commercial value of sulphur deposits at Damon Mound. The result of this test was evidently unsatisfactory, for the Union Sulphur Company abandoned further work and withdrew from the field.

The present (December, 1924) daily production of Damon Mound totals 1,325 barrels, all of which is obtained from fifty-three wells; fifty-one are on the southwestern side and two on the northeastern side. All wells are pumped, and about 32 per cent of the fluid obtained is water. Production has reached a settled stage and is slowly declining.

Development to date has resulted in the discovery of two producing areas located, respectively, on the southwestern and northeastern flanks of the dome. The major portion of oil was produced on the southwestern side, the northeastern side giving wells of low initial production and short life. The combined area of the two fields covers about 260 acres and yielded 5,008,870 barrels of oil prior to the year 1924.

A total of 291 wells were drilled at Damon Mound, 85 of which produced oil, 154 were non-productive, and the remaining 52 completed as sulphur tests. Since these sulphur tests are shallow and were drilled solely for the purpose of exploring sulphur deposits, we can separate this work from that of wells drilled for oil.

A summary of the statistics of Damon Mound oil wells shows that the average well came in with an initial production of 466 barrels and produced a total of 58,927 barrels from a depth of 2,416 feet. See Table III.

PHYSIOGRAPHY

Damon Mound is located midway between Brazos and San Bernard rivers, both of which have cut deep channels in an almost featureless prairie. The surrounding country is typical of the Gulf coastal plain and slopes gently toward the Gulf at an average rate of 1½ feet per mile.

The mound is one of the most conspicuous topographic features of the Texas coastal plain, and can be observed from all directions for a distance of many miles. It rises 83 feet above the surrounding prairie to a maximum elevation of 140 feet, the high point being in blocks 13 and 14 of the Wisdom subdivision, 2,700 feet north of the center of the mound. The mound is oval in shape and covers an area of 1,670 acres. The major axis is 12,000 feet long and extends N. 34° W., the minor axis being 8,250 feet at right angles.

Radial drainage lines extend in all directions down the sides of the mound. Erosion has been active, and the surface is unevenly

TABLE III

DEVELOPMENT AT DAMON MOUND

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
J. M. Guffey	Herndon	1	1901	Dry	1,160	Salt 573–1,160 ft.
J. M. Guffey	Mulcahy	1	1901	Dry	1,097	Abandoned in hard lime
Damon Mound Oil & P. L. Co.	Mulcahy	1	1902	Dry	1,230	Abandoned in sand and clay
J. M. Guffey	Mulcahy	2	1902	Dry	1,380	No data
R. F. Mulcahy	Mulcahy	1	1904	Dry	250	Abandoned in hard rock
Damon Humble Oil Co.	Clark	1	1916	Dry	949	Junked
Damon Humble Oil Co.	Howell	1	1916	Dry	800	Junked
Producers Oil Co.	Howell	1	1916	Dry	3,085	Tested salt water
Texas Exploration Co.	Becker	1	1916	Dry	1,580	Abandoned in blue clay
Texas Exploration Co.	Fordtram	1	1916	Dry	550	Abandoned in salt
Texas Exploration Co.	Mayes	1	1916	Dry	695	Abandoned in salt
Texas Exploration Co.	Mayes	2	1916	Dry	521	Abandoned in gypsum
Texas Exploration Co.	Mulcahy	1	1916	Dry	797	Salt 587–797 ft.
Texas Exploration Co.	Thomas	1	1916	Dry	1,785	No data
Texas Exploration Co.	Wallace	1	1916	Dry	650	Salt 600–50 ft.
Texas Exploration Co.	Wallace	2	1916	Dry	573	Salt 565–73 ft.
Texas Exploration Co.	Wallace	3	1916	Dry	410	Abandoned in gypsum
Texas Exploration Co.	Wisdom	1	1916	100	1,953	Salt 1,000–1,953 ft.
Texas Exploration Co.	Wisdom	2	1916	Dry	986	Junked in hard rock
Texas Exploration Co.	Wisdom	3	1916	Dry	865	Salt 855–65 ft.
Couch *et al.*	Gierson	1	1917	300	1,527	19° gravity oil
Couch *et al.*	Gierson	2	1917	300	1,551	20° gravity oil
Cummings & Wilkerson	Cushing	1	1917	Dry	910	Abandoned in heaving shale
Cummings & Wilkerson	Mulcahy	1	1917	Dry	550	Junked
Damon Humble Oil Co.	Clark	2	1917	Dry	1,030	No data
General Petroleum Co.	Bryan	1	1917	Dry	1,480	Tested salt water
General Petroleum Co.	Bryan	2	1917	Dry	1,400	Junked
Humble Oil & Ref. Co.	Allen	1	1917	Dry	399	Gypsum 393–99 ft.
Humble Oil & Ref. Co.	Allen	2	1917	Dry	1,513	Abandoned in salt

Humble Oil & Ref. Co.	Bryan	1	1917	350	1,487	50 per cent water and basic sediment
Humble Oil & Ref. Co.	Bryan	2	1917	500	1,574	50 per cent water and basic sediment
Humble Oil & Ref. Co.	Bryan	3	1917	Dry	675	
Producers Oil Co.	Cave	1	1917	Dry	385	Gypsum 375–85 ft.
Producers Oil Co.	Cave	2	1917	Dry	547	Salt 540–47 ft.
Producers Oil Co.	Howell	2	1917	Dry	3,530	Show of oil at 1,540 ft.
Success Oil Co.	Lowe	1	1917	Dry	1,737	Tested salt water
Success Oil Co.	Lowe	2	1917	200	1,695	80 per cent water and basic sediment
Swift Oil & Sulphur Co.	Freeman	1	1917	Dry	505	Show of oil at 447 ft.
Tarber Oil Co.	Bryan	1	1917	Dry	1,885	Abandoned in shale
Tarber Oil Co.	Bryan	2	1917	Dry	345	Abandoned in lime rock
Tarber Oil Co.	Hankamer	1	1917	Dry	341	Abandoned in lime rock
Texas Exploration Co.	Becker	2	1917	Dry	3,579	Abandoned in lime rock
Texas Exploration Co.	Bryan, J. L.	1	1917	500	1,557	24° gravity oil—18 per cent water and basic sediment
Texas Exploration Co.	Bryan, T. H.	1	1917	3,500	3,473	20° gravity oil—90° F.
Texas Exploration Co.	Bryan, T. H.	2	1917	Dry	144	Gypsum rock 128–44 ft.
Texas Exploration Co.	Bryan, T. H.	3	1917	7,500	1,449	24° gravity oil
Texas Exploration Co.	Bryan, T. H.	4	1917	250	1,717	24° gravity oil—100° F.
Texas Exploration Co.	Bryan, T. H.	5	1917	Dry	1,723	Junked in rock
Texas Exploration Co.	Cave Heirs	AA-21	1917	Dry	1,080	Abandoned in gumbo and gypsum
Texas Exploration Co.	Cave, Nellie	1	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Cave, Nellie	2	1917	Dry	583	Abandoned in salt
Texas Exploration Co.	Cave, W. M.	Y-19	1917	Dry	545	Abandoned in gypsum
Texas Exploration Co.	Cave, W. M.	Y-21	1917	Dry	533	Abandoned in gypsum
Texas Exploration Co.	Cave, W. M.	Y-23A	1917	Dry	637	Salt 634–37 ft.
Texas Exploration Co.	Community	1	1917	Dry	555	Salt 550–55 ft.
Texas Exploration Co.	Damon L. Z.	R-18A	1917	Dry	525	Abandoned in gypsum
Texas Exploration Co.	Damon, M.	1	1917	Dry	1,841	Junked in rock
Texas Exploration Co.	Damon, M.	2	1917	200	1,710	19° gravity oil—4 per cent water and basic sediment
Texas Exploration Co.	Damon, M.	3	1917	Dry	1,720	Tested salt water
Texas Exploration Co.	Farrell	1	1917	Dry	2,022	Abandoned in gypsum
Texas Exploration Co.	Gulf Smith	1	1917	Dry	2,026	Heaving shale 1,966–2,026 ft.
Texas Exploration Co.	Gulf Smith	1A	1917	Dry	1,919	Junked in sand rock
Texas Exploration Co.	Masterson	1	1917	Dry	1,548	Tested salt water
Texas Exploration Co.	Mayes	R-24-A	1917	Dry	545	Salt 535–45 ft.

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Texas Exploration Co.	Mayes	R-24-B	1917	Dry	554	Salt 553–54 ft.
Texas Exploration Co.	Mayes	R-25-A	1917	Dry	537	Salt 536–37 ft.
Texas Exploration Co.	Mayes	S-24-A	1917	Dry	477	Abandoned in gypsum
Texas Exploration Co.	Mayes	W-19	1917	Dry	475	Abandoned in gypsum
Texas Exploration Co.	Mayes	W-24-A	1917	Dry	546	Salt 544–46 ft.
Texas Exploration Co.	Mulcahy	2	1917	Dry	592	Salt 591–92 ft.
Texas Exploration Co.	Mulcahy	3	1917	Dry	584	Salt 579–84 ft.
Texas Exploration Co.	Mulcahy	4	1917	Dry	449	Abandoned in gypsum
Texas Exploration Co.	Mulcahy	5	1917	Dry	583	Salt 580–83 ft.
Texas Exploration Co.	Mulcahy	6	1917	Dry	578	Salt 564–78 ft.
Texas Exploration Co.	Mulcahy	7	1917	Dry	572	Salt 570–72 ft.
Texas Exploration Co.	Mulcahy	8	1917	Dry	561	Salt 551–61 ft.
Texas Exploration Co.	Mulcahy	9	1917	Dry	551	Salt 548–51 ft.
Texas Exploration Co.	Munson	1	1917	Dry	3,440	Abandoned in heaving shale
Texas Exploration Co.	Munson	2	1917	Dry	3,448	Abandoned in salt
Texas Exploration Co.	Thomas	1	1917	Dry	1,785	No data
Texas Exploration Co.	Wallace	O–21	1917	Dry	580	Salt 536–80 ft.
Texas Exploration Co.	Wallace	R-21A	1917	Dry	558	Salt 556–58 ft.
Texas Exploration Co.	Wallace	S-21A	1917	Dry	536	Abandoned in gypsum
Texas Exploration Co.	Wallace	4	1917	Dry	408	Abandoned in gypsum
Texas Exploration Co.	Wallace	5	1917	Dry	550	Abandoned in gypsum
Texas Exploration Co.	Wallace	6	1917	Dry	605	Abandoned in salt
Texas Exploration Co.	Wallace	7	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wallace	8	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wallace	9	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wallace	10	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wisdom	4	1917	Dry	1,514	Junked
Texas Exploration Co.	Wisdom	4A	1917	Dry	1,459	Salt 1,416–59 ft.
Texas Exploration Co.	Wisdom	5	1917	Dry	3,529	Junked in hard sand
Texas Exploration Co.	Wisdom	6	1917	Dry	558	Salt 553–58 ft.

Texas Exploration Co.	Woodward	1	1917	Dry	1,560	Tested salt water
Texas Exploration Co.	Woodward	2	1917	Dry	1,445	Junked in hard rock
Webber & Andegree	Lucas	1	1917	Dry	1,045	Little dry gas
Adams Oil Association	Tarleton	1	1918	Dry	1,019	
Atkinson Oil Co.	Bryan	1	1918	25	1,420	
Atkinson Oil Co.	Bryan	2	1918	Dry	1,500	Tested salt water
Cummings & Wilkerson	Mulcahy	2	1918	Dry	915	Abandoned in heaving shale
Cummings & Wilkerson	Mulcahy	3	1918	Dry	717	Abandoned in heaving shale
Denver Oil Co.	Bryan	1	1918	Dry	2,208	Abandoned in hard rock
General Petroleum Co.	Bryan	4	1918	10	1,590	Flooded by salt water
General Petroleum Co.	Lockwood	1	1918	Dry	3,051	No data
Glen Petroleum Co.	Centex	1	1918	Dry	2,210	Junked
Gulf Prod. Co.	Robertson	1	1918	57	1,600	
Gulf Prod. Co.	Robertson	2	1918	Dry	1,628	Junked in hard rock
Humble Oil & Ref. Co.	Bryan	3A	1918	Dry	680	Junked in hard rock
Humble Oil & Ref. Co.	Bryan	3B	1918	Dry	512	Junked in hard rock
Humble Oil & Ref. Co.	Bryan	3C	1918	Dry	1,502	Tested salt water
Humble Oil & Ref. Co.	Bryan	4	1918	225	1,527	10 per cent water and basic sediment
Humble Oil & Ref. Co.	Bryan	5	1918	22	1,573	
Humble Oil & Ref. Co.	Gallaher	1	1918	Dry	3,247	Tested salt water
Hyde Prod. Co.	Bryan	1	1918	Dry	1,664	Tested salt water
Mankers Oil & Ref. Co.	Bryan	1	1918	40	1,525	Flooded by salt water
Royal Oil & Ref. Co.	Bryan	1	1918	25	1,450	5 per cent water and basic sediment
Royal Oil & Ref. Co.	Bryan	2	1918	30	1,534	
Sinclair Oil & Gas Co.	Bryan	11	1918	50	1,580	
Sinclair Oil & Gas Co.	Masterson	6	1918	10	2,085	Production at 1,448 ft.
Sinclair Oil & Gas Co.	Norton	1	1918	Dry	4,229	Abandoned in sand and shale
Sinclair Oil & Gas Co.	Ptak	1	1918	Dry	4,625	Little 25° gravity oil
Sinclair Oil & Gas Co.	Thomas	2	1918	Dry	3,280	Little oil at 3,152 ft.
Sinclair Oil & Gas Co.	Wisdom	7	1918	Dry	2,422	Junked in hard sand
Success Oil Co.	Hillyer	1	1918	Dry	2,835	Tested salt water
Success Oil Co.	Lowe	3	1918	Dry	1,735	Tested salt water
Swift Oil & Sulphur Co.	Freeman	2	1918	Dry	634	
Swift Oil & Sulphur Co.	Freeman	3	1918	Dry	700	Salt 618–700 ft.
Swift Oil & Sulphur Co.	Horn	1	1918	Dry	2,600	

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Swift Oil & Sulphur Co.	Jackson	1	1918	Dry	2,237	Abandoned in rock
Texas Co.	Munson	1	1918	Dry	3,462	Little oil at 2,650 ft.
Texas Co.	Munson	2	1918	Dry	3,452	Abandoned in salt
Texas Exploration Co.	Becker	2	1918	Dry	3,566	Abandoned in lime rock
Texas Exploration Co.	Bryan	6	1918	225	2,493	Pipe-line oil
Texas Exploration Co.	Bryan	7	1918	Dry	1,640	Tested dry
Texas Exploration Co.	Bryan	8	1918	Dry	3,591	Abandoned in heaving shale
Texas Exploration Co.	Bryan	9	1918	Dry	2,308	
Texas Exploration Co.	Cave	X-23A	1918	Dry	548	Salt 545–48 ft.
Texas Exploration Co.	Cave	X-24A	1918	Dry	525	Abandoned in gypsum
Texas Exploration Co.	Damon, L. Z.	1	1918	Dry	1,841	Junked
Texas Exploration Co.	Damon, M	4	1918	200	2,490	
Texas Exploration Co.	Damon, M.	5	1918	Dry	1,588	
Texas Exploration Co.	Jackson	5	1918	Dry	2,093	Show of oil at 2,087 ft.
Texas Exploration Co.	Jackson	6	1918	Dry	742	Tested salt water
Texas Exploration Co.	Masterson	1	1918	Dry	681	Abandoned in salt
Texas Exploration Co.	Masterson	2	1918	Dry	2,453	Junked
Texas Exploration Co.	Masterson	3	1918	200	1,358	Heavy gas pressure
Texas Exploration Co.	Masterson	4	1918	300	1,667	
Texas Exploration Co.	Mayes	V-22A	1918	Dry	529	Abandoned in gypsum
Texas Exploration Co.	Mayes	W-22A	1918	Dry	562	Salt 560–62 ft.
Texas Exploration Co.	Mulcahy	10	1918	Dry	551	Salt 548–51 ft.
Texas Exploration Co.	Mulcahy	11	1918	Dry	579	Salt 577–79 ft.
Texas Exploration Co.	Ramdohr	1	1918	350	2,527	95 per cent water and basic sediment
Texas Exploration Co.	Wisdom	5A	1918	Dry	1,057	Junked
Texas Exploration Co.	Wisdom	O-22A	1918	Dry	775	Abandoned in salt
Texas Exploration Co.	Wisdom	O-23A	1918	Dry	546	Salt 544–46 ft.
Texas Exploration Co.	Wisdom	O-24A	1918	Dry	530	Salt 527–30 ft.
Texas Exploration Co.	Wisdom	O-24B	1918	Dry	530	Salt 529–30 ft.
Texas Exploration Co.	Wisdom	P-25A	1918	Dry	538	Salt 536–38 ft.

Texas Exploration Co.	Wisdom	S-24B	1918	Dry	562	Salt 561–62 ft.
Texas Exploration Co.	Wisdom	S-25A	1918	Dry	546	Salt 544–46 ft.
Texas Exploration Co.	Wisdom	T-25A	1918	Dry	545	Salt 544–45 ft.
Texas Exploration Co.	Woodward	3	1918	120	1,558	9 per cent water and basic sediment
Webber & Andegree	Lucas	2	1918	50	1,645	
Webber & Andegree	Lucas	3	1918	Dry	1,625	Junked
Sinclair Oil & Gas Co.	Becker	3	1919	Dry	3,435	Sand rock, show of light oil
Sinclair Oil & Gas Co.	Bryan	10	1919	Dry	2,835	
Sinclair Oil & Gas Co.	Bryan	12	1919	Dry	1,734	Junked in lime rock
Sinclair Oil & Gas Co.	Bryan	13	1919	Dry	1,728	Junked in lime rock
Sinclair Oil & Gas Co.	Jackson	8	1919	Dry	2,072	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Jackson	9	1919	100	1,529	19 ft. of hard oil sand
Sinclair Oil & Gas Co.	Kempner	1	1919	Dry	1,810	Salt 1,800–10 ft.
Sinclair Oil & Gas Co.	Masterson	7	1919	Dry	2,423	Junked
Sinclair Oil & Gas Co.	Masterson, N. T.	1	1919	Dry	2,410	
Sinclair Oil & Gas Co.	Masterson (trustee)	1	1919	150	2,298	Production at 1,640 ft.
Sinclair Oil & Gas Co.	Mayes	3	1919	Dry	3,022	Junked in hard rock
Sinclair Oil & Gas Co.	Norton	1	1919	Dry	4,229	Junked—show of oil 4,024 ft.
Sinclair Oil & Gas Co.	Sinclair (fee)	1	1919	Dry	1,358	
Sinclair Oil & Gas Co.	Thomas	3	1919	80	1,780	
Sinclair Oil & Gas Co.	Wisdom	8	1919	Dry	3,370	Tested salt water
Sinclair Oil & Gas Co	Wisdom	9	1919	Dry	1,584	Salt 1,579–84 ft.
Sinclair Oil & Gas Co.	Woodward	4	1919	Dry	2,027	Abandoned in salt
Humble Oil & Ref. Co.	Gallaher	2	1920	1,000	3,212	23° gravity oil
Humble Oil & Ref. Co.	Gallaher	3	1920	Dry	3,480	Salt 3,474–80 ft.
Sinclair Oil & Gas Co.	Becker	4	1920	Dry	1,960	Abandoned in salty shale
Sinclair Oil & Gas Co.	Bryan	14	1920	Dry	2,525	Show of oil at 2,450 ft.
Sinclair Oil & Gas Co.	Bryan	15	1920	4,000	3,103	23° gravity oil—80° F.
Sinclair Oil & Gas Co.	Bryan	16	1920	5,000	2,774	22.4° gravity oil—94° F.
Sinclair Oil & Gas Co.	Bryan	17	1920	Dry	2,631	Junked
Sinclair Oil & Gas Co.	Bryan	19	1920	Dry	2,330	Abandoned in shale
Sinclair Oil & Gas Co.	Duncan	1	1920	125	1,454	
Sinclair Oil & Gas Co.	Jackson	10	1920	Dry	1,574	Tested salt water

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Sinclair Oil & Gas Co.	Jackson	11	1920	120	1,812	20° gravity oil—85° F.
Sinclair Oil & Gas Co.	Masterson	8	1920	30	2,786	
Sinclair Oil & Gas Co.	Masterson	9	1920	10	1,542	Production at 1,350 ft.
Sinclair Oil & Gas Co.	Masterson	10	1920	5,000	3,256	21° gravity oil
Sinclair Oil & Gas Co.	Munson	1	1920	50	3,116	Flooded by salt water
Sinclair Oil & Gas Co.	Norton	2	1920	Dry	1,210	Junked
Sinclair Oil & Gas Co.	Ptak	2	1920	Dry	4,650	
Sinclair Oil & Gas Co.	Sinclair (fee)	1A	1920	Dry	2,134	
Sinclair Oil & Gas Co.	Thomas	4	1920	225	1,604	
Humble Oil & Ref. Co.	Damon	1	1921	Dry	468	Abandoned in gravel
Humble Oil & Ref. Co.	Gallaher	4	1921	Dry	3,758	
Humble Oil & Ref. Co.	Gallaher	5	1921	100	2,860	
Humble Oil & Ref. Co.	Kitchen	1	1921	Dry	4,540	Abandoned in heaving shale
Humble Oil & Ref. Co.	Mock	1	1921	Dry	3,553	Show of light oil
Hyde Prod. Co.	Damon, R.	1	1921	Dry	3,255	Abandoned in heaving shale
Oil Producers Co.	Damon, L. Z.	1	1921	Dry	2,410	Abandoned in gypsum
Poor Boy Oil Co.	Bellville	1	1921	Dry	2,940	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Bryan	17A	1921	Dry	2,625	
Sinclair Oil & Gas Co.	Bryan	18	1921	1,200	3,213	
Sinclair Oil & Gas Co.	Bryan	20	1921	Dry	3,377	Tested salt water
Sinclair Oil & Gas Co.	Bryan	21	1921	100	2,457	
Sinclair Oil & Gas Co.	Cummings	1	1921	Dry	2,550	Show of light oil
Sinclair Oil & Gas Co.	Masterson, N. T.	2	1921	Dry	2,087	Tested salt water
Sinclair Oil & Gas Co.	Masterson (trustee)	2	1921	500	1,700	
Sinclair Oil & Gas Co.	Robertson	1	1921	100	1,618	
Sinclair Oil & Gas Co.	Thomas	5	1921	50	3,280	
Sinclair Oil & Gas Co.	Williams	1	1921	100	1,762	
Southern Petroleum Co.	Bryan	1	1921	500	3,341	
Southern Petroleum Co.	Bryan	2	1921	Dry	3,108	Junked in rock
Southern Petroleum Co.	Norton	1	1921	Dry	3,625	Abandoned in heaving shale
Cullen Syndicate	Ward	1	1922	Dry	3,245	Abandoned in heaving shale

Cullen Syndicate	Ward	2	1922	Dry	3,355	Abandoned in heaving shale
Hyde Prod. Co	Gibson	1	1922	400	2,992	Pipe-line oil
Hyde Prod. Co	Gibson	2	1922	100	3,068	Production at 2,941 ft.
Hyde Prod. Co	Hillyer	1	1922	Dry	3,650	Heaving shale 3,618–50 ft.
Hyde Prod. Co	Kittrell	1	1922	125	3,170	21° gravity oil
Hyde Prod. Co	Kittrell	2	1922	Dry	3,184	Abandoned in black shale
Hyde Prod. Co	Lockwood	1	1922	Dry	4,014	Abandoned in hard sand
Hyde Prod. Co	Damon, R.	2	1922	Dry	3,823	Heaving shale 3,539–3,823 ft.
Hyde Prod. Co	Wisdom	1	1922	200	3,828	
Sinclair Oil & Gas Co	Bryan	22	1922	50	2,998	
Sinclair Oil & Gas Co	Bryan	23	1922	Dry	2,768	Junked
Sinclair Oil & Gas Co	Bryan	24	1922	150	3,414	
Sinclair Oil & Gas Co	Bryan	25	1922	150	3,055	
Sinclair Oil & Gas Co	Bryan	26	1922	Dry	3,313	Abandoned in heaving shale
Sinclair Oil & Gas Co	Bryan	27	1922	50	3,566	Production at 3,230 ft.
Sinclair Oil & Gas Co	Jackson	12	1922	200	2,983	
Sinclair Oil & Gas Co	Jackson	13	1922	80	1,950	
Sinclair Oil & Gas Co	Jackson	14	1922	Dry	3,492	Abandoned in heaving shale
Sinclair Oil & Gas Co	Lockwood	1	1922	Dry	3,790	Abandoned in heaving shale
Sinclair Oil & Gas Co	Masterson	11	1922	400	3,263	
Sinclair Oil & Gas Co	Masterson	12	1922	50	3,445	
Sinclair Oil & Gas Co	Masterson	13	1922	5	2,628	
Sinclair Oil & Gas Co	Masterson	14	1922	75	1,578	
Sinclair Oil & Gas Co	Masterson	15	1922	50	2,762	
Sinclair Oil & Gas Co	Masterson	16	1922	100	3,113	
Sinclair Oil & Gas Co	Masterson (trustee)	3	1922	100	2,012	
Sinclair Oil & Gas Co	Mock	1	1922	125	3,116	
Sinclair Oil & Gas Co	Munson	2	1922	Dry	3,524	Abandoned in heaving shale
Sinclair Oil & Gas Co	Williams	2	1922	Dry	2,253	Tested salt water
Sinclair Oil & Gas Co	Williams	3	1922	750	3,106	
Sinclair Oil & Gas Co	Williams	4	1922	100	2,995	Heaving shale at bottom
Sinclair Oil & Gas Co	Williams	5	1922	100	2,955	
Sinclair Oil & Gas Co	Williams	6	1922	15	3,252	Flooded by salt water
Sinclair Oil & Gas Co	Williams	7	1922	Dry	3,007	Abandoned in heaving shale
Southern Petroleum Co	Bryan	3	1922	500	3,458	
Southern Petroleum Co	Bryan	4	1922	Dry	3,175	Junked
Southern Petroleum Co	Bryan	5	1922	500	3,443	

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Southern Petroleum Co.	Japhet	1	1922	Dry	4,046	Abandoned in heaving shale
Union Sulphur Co.	Wallace	1	1922	Dry	347	Abandoned in gypsum
Union Sulphur Co.	Mayes	1	1922	Dry	499	Abandoned in rock
Union Sulphur Co.	Texas Ex. Co. (fee)	1	1922	Dry	509	Abandoned in gypsum
Union Sulphur Co.	Texas Ex. Co. (fee)	2	1922	Dry	574	Salt 567–74 ft.
Cullen Syndicate	Ward	3	1923	Dry	3,775	Abandoned in heaving shale
Hyde Prod. Co.	Atlantic	1	1923	80	3,528	Abandoned in heaving shale
Hyde Prod. Co.	Atlantic	2	1923	Dry	3,750	Heaving shale 3,680–3,750 ft.
Sinclair Oil & Gas Co.	Becker	5	1923	15	3,058	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Becker	6	1923	10	2,934	Heaving shale—production at 2,430 ft.
Sinclair Oil & Gas Co.	Becker	7	1923	Dry	3,340	Salt 2,955–3,340 ft.
Sinclair Oil & Gas Co.	Becker	8	1923	Dry	3,189	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Bryan	28	1923	30	2,438	
Sinclair Oil & Gas Co.	Bryan	29	1923	30	2,245	
Sinclair Oil & Gas Co.	Jackson	15	1923	100	2,907	
Sinclair Oil & Gas Co.	Jackson	16	1923	Dry	2,425	Junked in lime rock
Sinclair Oil & Gas Co.	Jackson	17	1923	Dry	3,883	
Sinclair Oil & Gas Co.	Jackson	18	1923	5–10	3,814	
Sinclair Oil & Gas Co.	Jackson	19	1923	Dry	3,127	Junked in lime rock
Sinclair Oil & Gas Co.	Jackson	20	1923	150	3,333	35° gravity oil
Sinclair Oil & Gas Co.	Masterson	17	1923	175	1,676	
Sinclair Oil & Gas Co.	Masterson	18	1923	75	1,745	
Sinclair Oil & Gas Co.	Mock	2	1923	250	3,590	
Sinclair Oil & Gas Co.	Mock	3	1923	100	3,416	
Sinclair Oil & Gas Co.	Proctor	1	1923	Dry	1,240	
Southern Petroleum Co.	Norton	2	1923	Dry	3,770	Tested salt water
Union Sulphur Co.	Texas Ex. Co.	3	1923	Dry	544	Abandoned in salt
Union Sulphur Co.	Mayes	2	1923	Dry	551	Salt 546–51 ft.
Union Sulphur Co.	Texas Ex. Co.	4	1923	Dry	668	Salt 648–68 ft.
Union Sulphur Co.	Wisdom	1	1923	Dry	745	Abandoned in gypsum
Union Sulphur Co.	Jackson	1	1923	Dry	528	Abandoned in gypsum

eroded into little hills or hummocks. The present topography, while corresponding in outline with the core of the dome, has no apparent relationship to the detail of subsurface structure. (Fig. 1.)

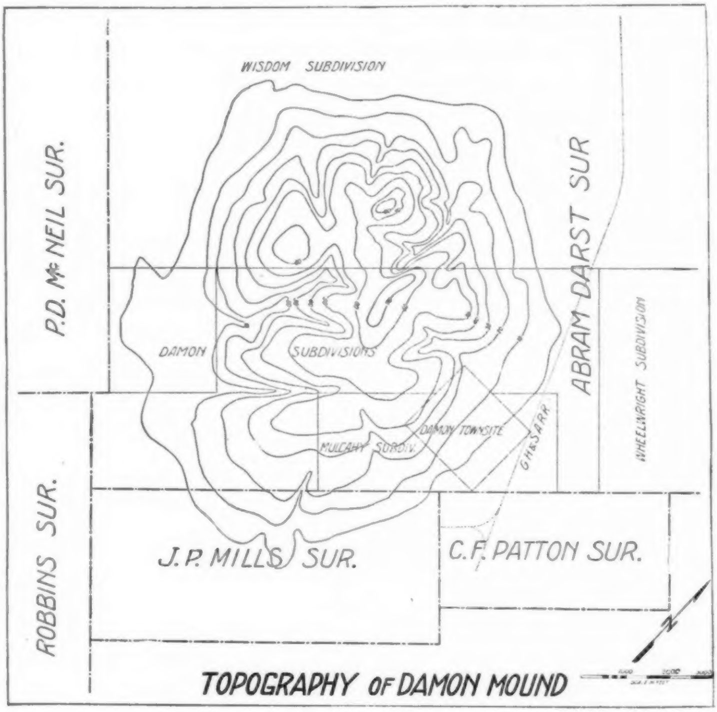


FIG. 1

GEOLOGY

Surface exposures are largely composed of red, blue, brown, and yellow clays with some sand and a little shale. The clays are calcareous and contain occasional limy concretions which weather out and collect in the bottom of drainage lines. The exposed formations are evidently a portion of the Beaumont clay, although some gravel was noted on the eastern side of the mound which has the appearance

of Lissie gravel. Surface formations are unconsolidated and apparently lie in a horizontal position, but do not display bedding-planes or other visible characteristics which could be used to determine the presence of structural deformation.

Subsurface conditions show the presence of an intrusive salt core capped by deposits of gypsum, anhydrite, and limestone. Adjacent formations are inclined at a steep angle sloping in all directions away from the salt.

SALT CORE

The upper extremity of the salt core is somewhat oval in outline, being essentially flat with rounded edges dipping to an unknown depth at an angle of about 83°. On the southwestern edge of the dome, immediately south of the oil field, there is an outlier of salt which extends beyond the generally symmetrical outline of the salt core. This outlier is probably an arm of salt which was squeezed out by unequal pressure. Core samples show that the salt plug is composed of almost pure rock salt containing waves and bands of darker material, indicating that flowage and adjustment has taken place under heavy pressure.

Forty-five wells have entered rock salt, the majority being shallow tests on top of the dome that only penetrated a few feet of this material. The greatest thickness of salt is shown in the Texas Exploration Company's No. 1 Wisdom from 1,000 to 1,953 feet. A sulphur test, O-24A, drilled by the Texas Exploration Company on the northwestern side of the dome, 4,500 feet from the center of the mound, shows the highest portion of salt so far recorded by any test in this field.

CAP ROCK

Cap rock is a term generally applied to mineralized deposits adjacent to and above the salt plug. These deposits are largely composed of gypsum, anhydrite, and limestone, varying in thickness in the central area from 375 to 575 feet, but thinning at the outer edges of the dome to a few feet. They are extremely irregular and occur rather as lenses, pockets, and concretions, no two sections being alike. There is, however, a general arrangement in which the major portion of deposits occur, in the order of gypsum below, limestone

at the top, with anhydrite between the two. The cap rock is generally porous and cavernous, containing variable amounts of sulphur, pyrite, calcite, and barite deposited in crystal form throughout the porous spaces. Some of the crystals have rounded edges, while others, particularly the calcite crystals, may be badly corroded, showing the effects of circulating underground waters. The upper portion of the cap rock is composed of hard limy material and is virtually a limestone, although inclusions of gypsum and anhydrite have been noted, together with an occasional thin parting of gumbo. Its thickness varies from 10 to 150 feet, but generally it does not occur as a solid mass. Well records show that the cap rock rises to within 68 feet of the surface, and it is believed that a portion of the cap rock may have extended to the surface on the eastern side of the mound, where limestone similar to cap rock was quarried and used for building purposes.

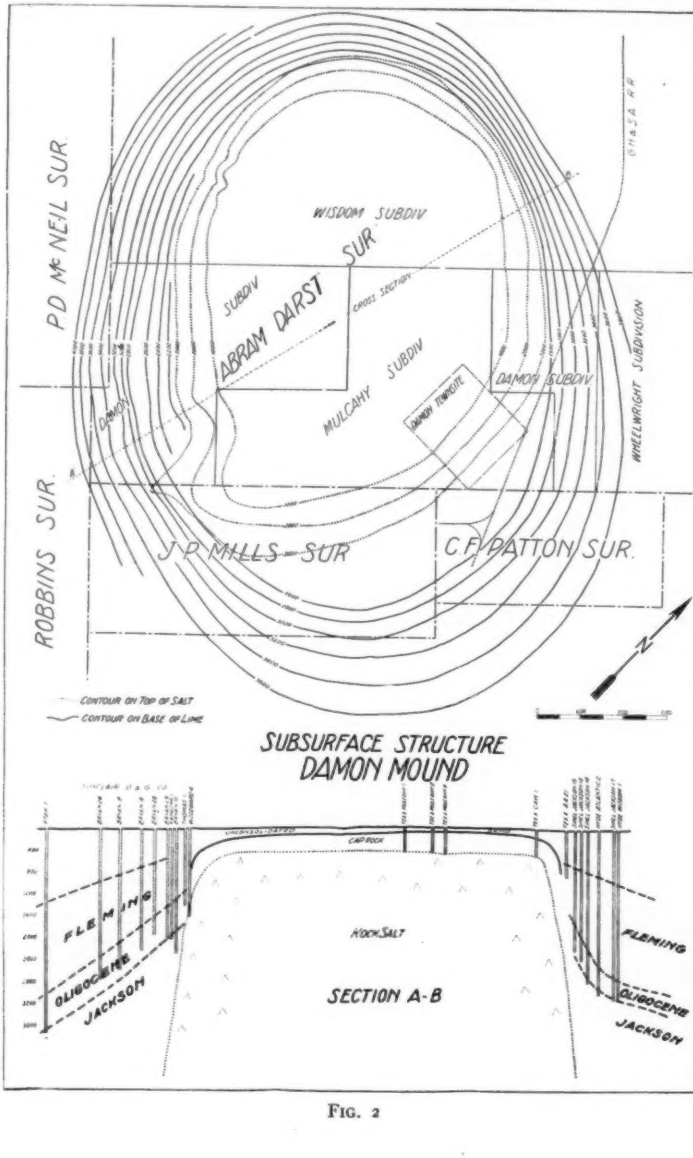
The log of a sulphur test shown in Table IV gives a good description of the cap rock.

STRUCTURE OF SURROUNDING SEDIMENTS

Eighteen hundred feet of structural displacement has been measured, and it is very probable that an additional amount can be proven by further deep drilling. Contour lines, as shown on Figure 2, represent the base of a limestone bed within the *Heterostegina* zone of the Oligocene formation. It furnishes an excellent key horizon for correlation purposes, and has been identified at many points around the major portion of the dome.

The sands within the producing area dip at an angle of about 40°, while formations on the opposite side, to the northeast, dip at a steeper angle, averaging about 60°. Dips of 23° have been recorded on the south, while those to the north approximate 47°.

Faulting.—Faulting is present, generally in the form of step faults extending along lines parallel to the circumference of the dome, the downthrow side being directionally away from the dome. Radial faulting has been noted, particularly in the southwestern flank, south of the old producing area. The presence of faulting can be identified, but owing to the extremely complicated structural conditions, in which radical changes occur within narrow limits, it is



P D Mc NEIL SUR.
WISDOM SUBDIV
ABRAM DARST SUR
SUBDIV
CROSS SECTION
MULCAHY SUBDIV
DAMON TOWNSITE
DAMON SUBDIV
WHEELWRIGHT SUBDIVISION
DAMON
ROBBINS SUR.
J P MILLS SUR
C F PATTON SUR.
N
CONTOUR ON TOP OF SALT
CONTOUR ON BASE OF LIME
SUBSURFACE STRUCTURE
DAMON MOUND
CAP ROCK
ROCK SALT
FLEMING
OLIGOCENE
JACKSON
SECTION A-B

FIG. 2

TABLE IV

TEXAS EXPLORATION COMPANY WELL NO. R-24b

Depth (Feet)	Formation
22	Sand
48	Yellow clay
67	Yellow clay, gravel, and blue gumbo
68	Limerock
80	Gypsum and limerock, lost returns at 72 feet
85	Limerock, losing returns
88	Sandy gypsum
101	Limerock, lost returns
106	Limerock and gypsum
116	Limerock
135	Lime and pyrite
170	Limerock, trace of sulphur
171	Blue gumbo
173	Limerock
178	Blue gumbo
181	Limerock
185	Shale and gypsum, trace of sulphur
192	Limerock, trace of sulphur
195	Limerock and pyrites
206	Broken limerock
209	Limerock and pyrites
220	Limerock and pyrites, trace of sulphur
235	Broken gypsum
245	Gypsum, very good showing of sulphur
254	Gypsum, 3 per cent of sulphur
260	Gypsum and anhydrite, 5 per cent sulphur
265	Gypsum and anhydrite, 10 per cent sulphur
270	Gypsum and anhydrite, 20 per cent sulphur
275	Gypsum and anhydrite, 15 per cent sulphur
280	Gypsum and anhydrite, 15 per cent sulphur
284	Gypsum and anhydrite, 15 per cent sulphur
297	Gypsum and anhydrite, 3 per cent sulphur
301	Gypsum and anhydrite, 2 per cent sulphur
310	Gypsum, anhydrite, and good showing of sulphur
315	Gypsum and sulphur, 1 foot will run 15 per cent and the rest a good trace
325	Gypsum with good showing of sulphur
343	Gypsum with trace of sulphur
345	Gypsum and sulphur showing
355	Gypsum and sulphur 5 per cent

TABLE IV—*Continued*

Depth (Feet)	Formation
365	Gypsum and sulphur showing
391	Gypsum and sulphur 2 per cent
405	Gypsum and trace of sulphur
455	Smooth gypsum and trace of sulphur
463	Smooth gypsum
479	Compact gypsum
484	Gypsum some transparent
513	Compact gypsum
534	Cavity
535–36	Gypsum, 50 per cent sulphur, loose formation
542	Sidetracked after twisted off
543	Loose formation, sulphur
552	Cavity
553	Gypsum, 50 per cent sulphur
554	Salt

difficult to define any particular fault or zone of faulting with accuracy. Crushed and shattered zones are present usually at the point of contact between the salt plug and surrounding sediments, indicating that considerable movement has taken place under heavy pressure. Wells in this zone are extremely variable, difficult to drill, and usually unproductive.

Faulting at Damon Mound is the result of displacement, induced by an upthrust from below. The force is believed to have been applied gradually over an extended period of time, creating faults at a comparatively slow rate, and not as sudden movement or slippage. Core samples from the faulted zone do not indicate the effect of heat such as would be expected were the fault created by sudden movement.

Heaving shale.—Heaving shale is a term applied to shaly material which rises or heaves within a drilling well. It occurs at many points adjacent to and surrounding the dome, but occasionally rises within faulted areas or paths of least resistance above its normal position. The shale is black to dark gray in color and usually belongs to the Jackson formation; however, some instances have been noted where shales of Oligocene age heaved in a similar manner, and it is believed that any material of shaly nature, regardless of age, will heave when subjected to heavy pressure.

STRATIGRAPHY

Lateral beds surrounding the dome are divided, for convenience of description, into the Jackson, Oligocene, Fleming, and overlying sediments.

Jackson.—Deposits of Jackson age are largely composed of dark-colored shales and clays with an occasional sandy member. The shales heave badly within a drilling well, and for this reason are frequently referred to as "heaving shale." They are somewhat carbonaceous and contain an occasional show of oil and gas, but do not produce in commercial quantities at Damon Mound. The top of the Jackson dips away from the dome at an angle of about 45°. In the Sinclair Oil and Gas Company's Becker No. 7, 559 feet of Jackson material is recorded, this figure representing about 410 feet of actual Jackson formation.

Oligocene.—The Oligocene is divided into three portions, described in the order of their deposition, as the *Marginulina*, *Heterostegina*, and *Discorbis* zones. They represent the Middle and Lower Oligocene, the Upper Oligocene being absent or eroded before the deposition of Fleming sediments. These deposits consist largely of limestones, shales, sands, and clays, representing a thickness of 560 feet near the dome and 750 feet at the outer edges of the field. The base of the Oligocene dips at an angle of about 45°. The Oligocene supplies the major portion of oil produced at Damon Mound. The *Heterostegina* and *Marginulina* zones are particularly rich in petroleum deposits.

Fleming.—The Fleming formation rests unconformably upon the Oligocene. It embraces the Miocene and a portion of the Pliocene formations, and is composed of calcareous clays with concretions, sands, and shales. The thickness varies from 1,000 feet near the dome to 1,750 feet at the outer edges of the field. The base of the Fleming slopes away from the salt plug at an angle of about 40°. Shows of oil and gas occur within its lower portions, and some oil was produced from this horizon on the southwestern side of the dome.

Overlying sediments.—Sediments overlying the Fleming and extending to the surface are of Pleistocene and Pliocene age. They consist in part of fluvatile and shallow-water deposits, comprising a series of sands, gravels, and clays containing an occasional log or bit

of buried driftwood. These deposits are lenticular and extremely variable as to character. The thickness averages about 1,400 feet, and the base of the formation dips at an angle of about 15°.

GEOLOGIC HISTORY

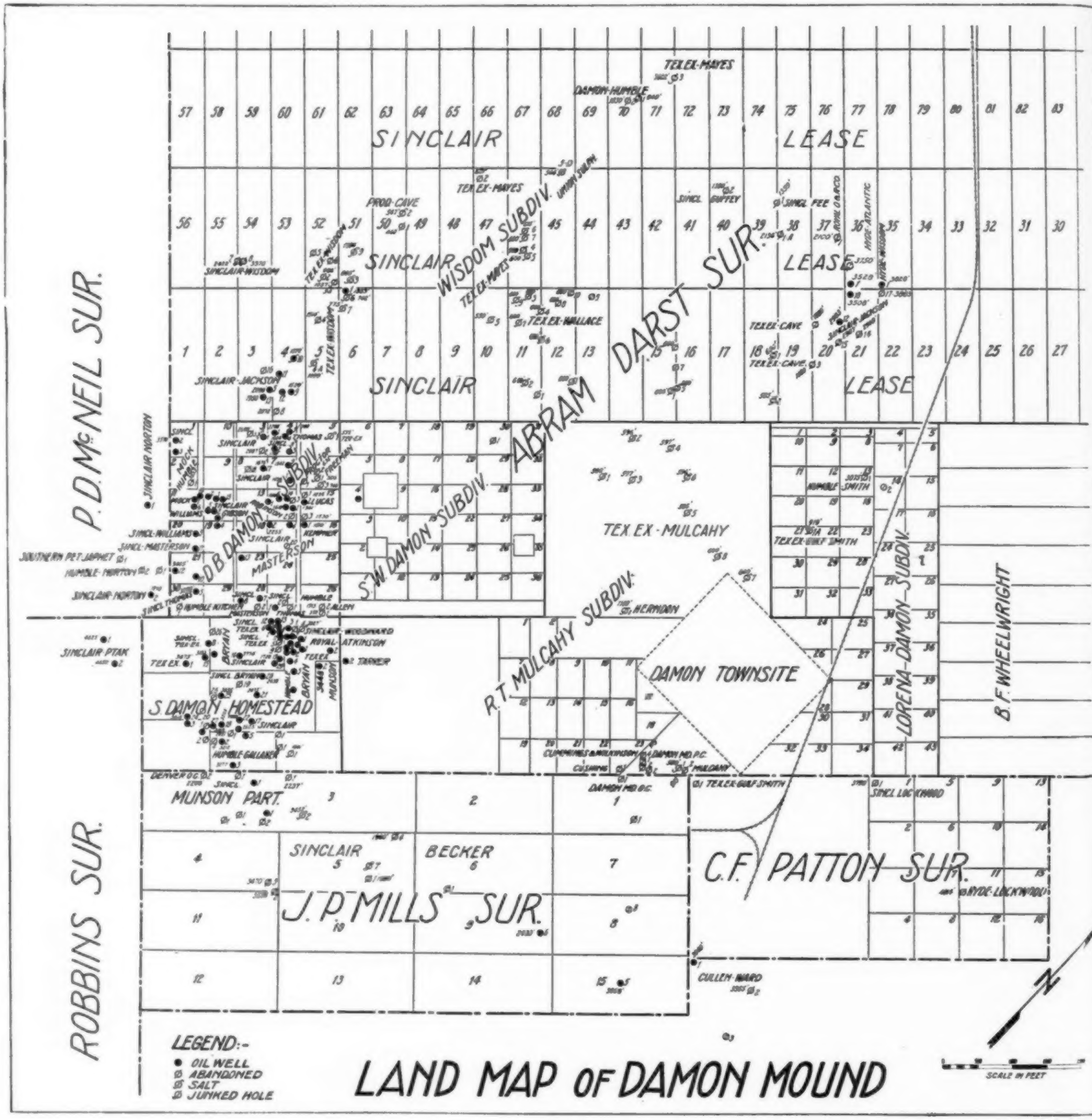
The maximum structural displacement occurred at or about the transitional period between the Pliocene-Miocene deposition, and continued with decreasing intensity to the time of Beaumont City deposition. Evidence of movement is indicated during Miocene times and possibly at an earlier period. A small amount of readjustment is believed to be taking place at the present time, for the reason that in 1921 a group of five wells on the Masterson tract suddenly quit producing on account of collapsed casing. No observations have been made to establish the possibility of present-day growth.

ORIGIN OF THE DOME

Damon Mound, although differing in some of its details, is nevertheless a typical salt dome similar to many others of its type. It was formed at about the same time and displays many of the characteristics common to other salt domes of the Gulf Coast district. Its origin is a subject upon which we may draw certain conclusions from conditions believed to exist at great depths. Several theories have been advanced, and since the writer has not observed any conclusive evidence which would add to our present knowledge of salt-dome origin, he therefore refers the reader to discussions already published by students of this subject.

ORIGIN OF THE CAP ROCK

The Damon Mound salt dome penetrates intrusively the surrounding formations. These formations have been cut or broken, permitting an intimate association of included waters with the salt plug. The water is under a static head, subject to minor movements of the dome, and has no doubt dissolved and redistributed a portion of the soluble material according to locally varying conditions and the laws of solubility. In view of the above, it is believed that the mineralized material, such as gypsum, anhydrite, cap rock, sulphur, etc., above the salt is derived from solutions as a precipitate deposi-


SINCLAIR LEASE
SINCLAIR LEASE
SINCLAIR LEASE
WISDOM SUBDIV.
ABRAM DARST SUR.
P. D. McNEIL SUR.
D. B. DAMON SUBDIV.
S. W. DAMON SUBDIV.
TEX. EX. - MULCAHY
R. T. MULCAHY SUBDIV.
DAMON TOWNSITE
LORENA-DAMON-SUBDIV.
B. F. WHEELWRIGHT
S. DAMON HOMESTEAD
MUNSON PART.
SINCLAIR
BECKER
J. P. MILLS SUR.
C. F. PATTON SUR.
ROBBINS SUR.
LEGEND:-
OIL WELL
ABANDONED
SALT
JUNKED HOLE
SCALE IN FEET
LAND MAP OF DAMON MOUND

tion or replacement, and that the character and extent of this material is governed by local conditions and subsequent movements of the dome. The presence of faulting within the cap rock indicates that movement must have taken place after the cap rock was formed.

OIL DEPOSITS

The productive area at Damon Mound is distributed as shown on Plate 9, and represents about 15.5 per cent of the total area of the mound. The oil is believed to originate within bituminous shales of the Jackson, Oligocene, and Miocene formations, and to have later migrated into adjacent sandy horizons. The majority of the so-called oil sands are really admixtures of sand, shale, and clay, divided by partings of clay. They are lenticular, extremely variable as to character, and frequently change within narrow limits. Faulting is believed to play an important rôle in the accumulation of oil, and probably serves as an effectual barrier, retaining the oil on the downthrow side.

The character of oil varies according to location. Heavy oil of asphaltic base and a consistency almost like that of tar is reported to occur in the upper portions of the cap rock and in sands adjacent to the cap rock. Oil of 35° Baumé was produced from a depth of 650 feet in the Texas Exploration Company's No. 1 Wisdom on the western side of the mound. The Sinclair Oil and Gas Company obtained several hundred barrels of 34.5° Baumé oil, containing both paraffin and asphalt, at 3,334 feet in their No. 20 Jackson, 2,500 feet south of the Wisdom well.

Variations of gravity in the old producing area, on the southwestern side of the dome, range from 19° Baumé in the Texas Exploration Company's No. 1 Gierson at 1,525 feet, to 25° Baumé in the Sinclair Oil and Gas Company's No. 1 Ptak at 4,625 feet.

ANALYSIS OF OIL

Table V gives an analysis of oil obtained from the Sinclair Oil and Gas Company's No. 15 Bryan, which is representative of the oil produced at Damon Mound.

A test of mixed oil from several wells on the southwestern side of the field gives the analysis shown in Table VI.

PRODUCTION

Production curves.—The field-production curve, if we may call it a curve, is little more than an irregular group of sharp peaks and

TABLE V

Gravity	23.8° Baumé	Pour	0
Flash (Cleve)	180	Basic sediment and water	0.1 per cent
Fire	235	Sulphur	0.103
Viscosity at 100° C.	94	Color	Green

DISTILLATION

Per Cent	Temperature F.	Gravity Baumé	Per Cent	Temperature F.	Gravity Baumé
Start	302		45	590	23.9
5	440	36.8°	50	613	23.1
10	468	31.6	60	649	22.5
15	487	29.7	65	657	23.2
20	504	29.6	70	660	24.5
25	517	27.7	75	665	25.2
30	536	26.5	80	676	25.3
35	553	25.8	85	680	25.1
40	571	24.9			

Pour at end, 65° F.

depressions, influenced by the performance of individual wells. However, it tells us in graphic form the story of Damon Mound produc-

TABLE VI

Gravity	21.8° Baumé
Flash	200
Viscosity at 100° C.	130
Pour	0
Basic sediment and water	.5 per cent
Italian tar test	.6 per cent
Color	Green

Refining Yields

	Per Cent
Naptha	2
Gas oil	45
Lubricating oil	36
Fuel oil	14
Loss	3

tion by months, for a period of seven years ending December 31, 1924. The crest of the curve was reached during the month of

December, 1920. From that time to the present, decline has been the rule. At the end of 1922, this decline amounted to 53 per cent; at the end of 1923, 64 per cent; and judging from the present rate of production, the decline of 1924 should closely approximate 73 per cent.

The decline of initial production per well is correspondingly sharp, and the decrease of pressure within the producing horizon has reached a point where it is now necessary to pump all wells. No two wells produce alike, but the majority show high initial production with rapid decline, the curve flattening out into an irregular line of low gradient extending for a period of several years. The performance of an individual well is largely governed by the character of the producing horizon, mechanical condition of the well, and the method of operation. Fine sand or sticky shale sometimes clogs the screen or causes a "sanded" condition which interferes with the natural flow of oil. Improper screen-settings, leaking casing-seats, split casing, and other mechanical defects also alter the performance of the well. The practice of controlling the rate of initial flow in large wells by means of chokers results in a decline curve which does not represent the true performance of the well under open-flow conditions.

Figures 3, 4, and 5 show the monthly production of the Humble Oil and Refining Company's Nos. 1 and 2 Bryan and No. 2 Gallagher.

Drilling and production methods.—All wells are drilled by the rotary method, using a fish-tail or roller bit as the occasion demands. Casing is generally set in gumbo or rock immediately above the producing horizon, with from one to seven joints of screen according to the thickness and distribution of the producing sand. The gauge of screen is usually 80-mesh. The cost of drilling and completing a 3,000-foot well, including all items of expense, approximates $25,000.

The initial production of flowing wells is generally free from water and emulsion, but the oil from all wells eventually requires dehydration. The Tret-o-lite system is used for this purpose. The dehydrated oil is transferred into storage tanks and later pumped through a pipe line to West Columbia, and into the main line of the Sinclair Pipe Line Company, which extends to the Sinclair Refinery at Sinco.

SULPHUR

Sulphur deposits were discovered at Damon Mound in 1916, and since that time fifty-two wells have been drilled and a steaming test

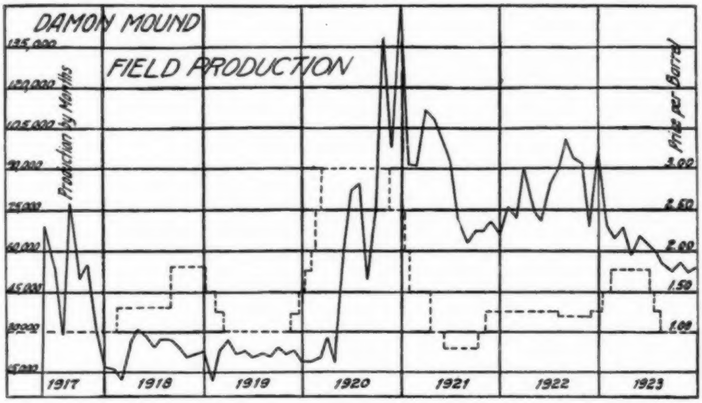


FIG. 3

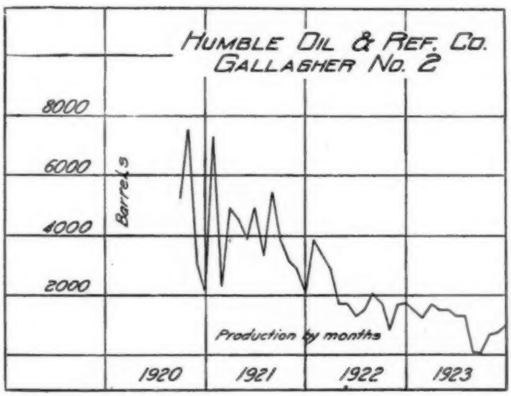


FIG. 4

made in the field to determine the value of these deposits. All wells were drilled with a rotary rig, using the core barrel at frequent intervals. In fact, all important sulphur-bearing horizons were cored throughout.

The areal distribution of the sulphur has been determined, and although traces occur at many points on the dome, the only deposit of importance is confined to an area of 120 acres on the northern portion of the mound.

The sulphur occurs below the limestone and extends downward at intervals to within a few feet of the salt core. The principal sulphur-bearing horizon lies about midway between the limestone and top of the salt. Sulphur is disseminated in crystal form throughout the porous spaces of gypsum and anhydrite deposits, as a secondary or replacement deposit. The crystals vary in size from small forms to several inches in length, and the sulphur is very pure. Several

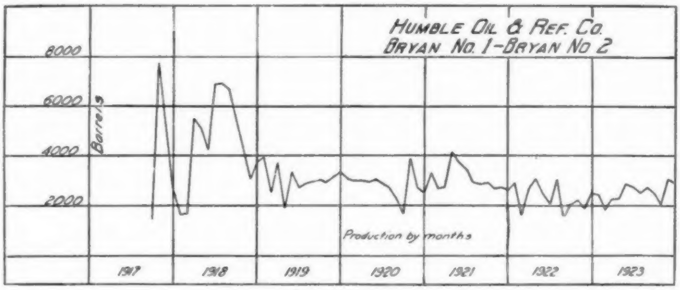


FIG. 5

theories have been advanced to explain the presence of sulphur deposits in dome material, and although nothing has been proven definitely, it is generally believed that they were formed from gypsum and anhydrite by a reducing medium such as petroleum or other hydrocarbon. The presence of heavy oil in and above the cap rock may indicate that such a reaction has taken place.

The total thickness of sulphur is shown by contour lines on Figure 6. These lines express the combined sulphur content in feet as though it were present in one solid bed of pure sulphur.

CONCLUSION

In conclusion it may be added that the upper portion of the dome does not offer sufficient inducements to warrant further drilling for oil. This area is confined within the 1,000-foot contour on the salt and probably extends a little beyond its southern limits. Approxi-

mately one-third of all wells drilled at Damon Mound are located in this area. These tests are widely distributed and resulted in failures at every point. No productive horizons were found, and the underlying formations are extremely variable and apparently broken.

If new sources of supply are to be found, we must look for them in untested areas around the periphery of the dome. The periphery has been fairly well tested with the exception of an area on the north and northwestern sides, extending around the dome for a distance of

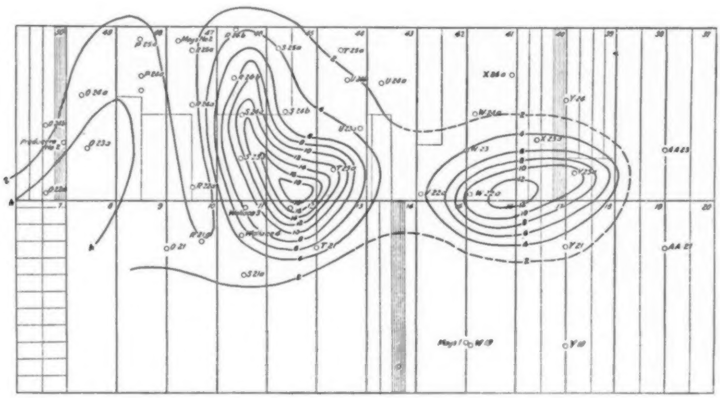


FIG. 6.—Contours showing aggregate thickness of sulphur, Damon mound.

6,000 feet. It is possible that commercial production may be found within this area. However, steep dips are present at both ends, and they no doubt indicate that if oil is found, the productive area will be confined to a rather narrow strip surrounding the salt plug. Forty per cent of all wells drilled on the periphery of the Damon Mound salt dome obtained oil. Commercial production is not to be expected from available formations below the Oligocene.

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THE SALT DOMES OF SOUTH TEXAS[1]

DONALD C. BARTON[2]

ABSTRACT

In south Texas, there are three known salt domes, Palangana, Piedras Pintas, and Falfurrias; three possible domes, Sal del Rey, Sal Vieja, and Chapeño; and two much less probable domes, Smith Corkill and La Lomita. The structure of Palangana, fairly well known from drilling, is that characteristic of an American salt dome, and is distinctly reflected in the topography. Palangana has no production. At Piedras Pintas, the salt and cap have been drilled into, but not much is known in regard to the structure of the dome. Piedras Pintas has a small, shallow oil field. Both domes gives evidence of the very great upthrust of the salt. On the basis of the evidence afforded by the German salt domes, the origin of salt domes is the plastic deformation of sedimentary salt beds. The origin of salt domes is the plastic deformation of sedimentary salt beds. The origin of the cap, such as is present at both Palangana and Piedras Pintas, has not been satisfactorily explained, although several plausible theories have been proposed. At Falfurrias, the salt has not been encountered, but the presence of a characteristic salt-dome mound and characteristic cap rock indicate the presence of a salt dome. Sal del Rey and Sal Vieja are saline lakes whose topography in a general way is similar to that of a central-depression type of salt-dome mound. The lakes, however, are more probably due to wind activity with concentration of normal surface waters in the wind-scooped basins. Chapeño suggests salt-dome structure in the presence of sulphur deposits. La Lomita is a mound near the Rio Grande, and Smith Corkill is a group of chalcedonic knobs.

INTRODUCTION

In south Texas there are three known salt domes, Palangana, Piedras Pintas, and Falfurrias; and several possible domes, Sal del Rey, Sal Vieja, Chapeño (over the border in Mexico), and less probably Smith Corkill and La Lomita, which have some of the surface aspects of domes, but which are not proven domes (Fig. 1). Piedras Pintas and Falfurrias have long been known, but have not been well described.

SOURCES OF INFORMATION

Information concerning the south Texas domes and possible domes was obtained by personal work in the field by the author in the case of Palangana, Piedras Pintas, Falfurrias, Sal del Rey, Sal Vieja, detailed work by his assistant, O. H. Eichelberger, around Sal del Rey and Sal Vieja; descriptions by various geologists in the

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case of Chapeño; Mr. Deussen's report and descriptions by several geologists in the case of Smith Corkill; and Mr. Trowbridge's paper and descriptions by several geologists in the case of La Lomita. The

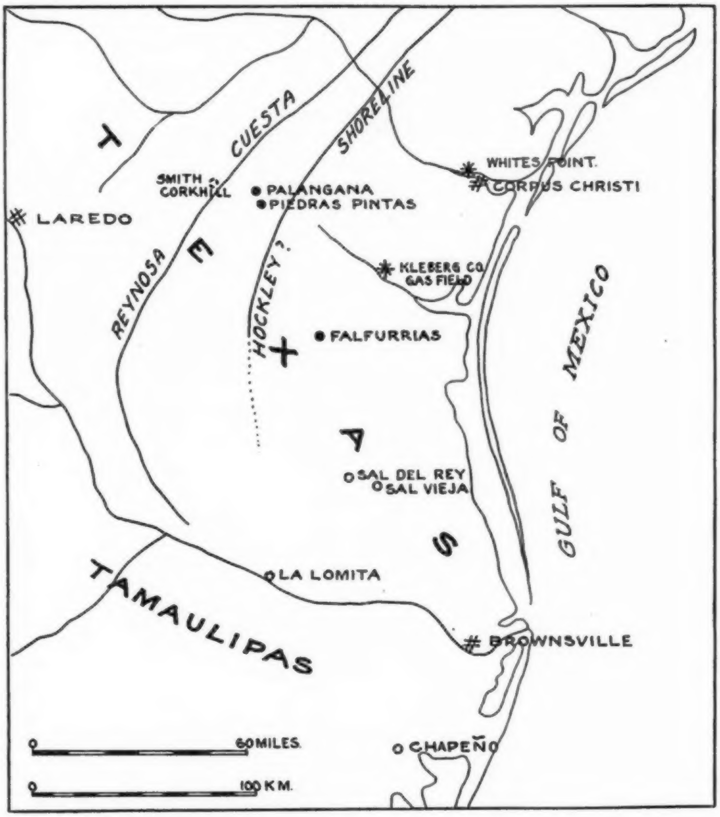

FIG. 1.—Sketch map showing position of the south Texas salt domes

author is indebted to the geological departments and geologists of the Sinclair Oil and Gas Company, the National Oil Company, the Empire Gas and Fuel Company, the Humble Oil and Refining Company, for well logs at Palangana and Piedras Pintas; and to Miss

Alva Ellisor, paleontologist of the Humble Oil and Refining Company, for stratigraphic data based on micropaleontological work; to David Donoghue for the data regarding the early history of Piedras Pintas; and to A. G. Wolff of the Texas Gulf Sulphur Company, to the Union Sulphur Company, and to A. H. Smith for the data regarding the development during 1924.

PALANGANA AND PIEDRAS PINTAS

INTRODUCTION

Location.—Palangana and Piedras Pintas are in the east central part of Duval County, about 110 miles due south of San Antonio, and about halfway between Laredo and Corpus Christi. Piedras Pintas lies at Noleda station, about 2 miles north-northeast of the small town of Benavides on the Texas Mexican Railway. Palangana is about 6 miles north of Benavides and 4 miles north-northwest of Piedras Pintas. Both domes are best reached by the Texas Mexican Railway, from Laredo, Robstown, or Corpus Christi to San Diego, which lies 15 miles east of the domes, or to Benavides, or from Laredo, Corpus Christi, or Robstown by automobile. There is a hotel at San Diego, and a railway eating-house with a few beds at Benavides.

History.—The Piedras Pintas shallow oil field is one of the oldest salt-dome oil fields. In August, 1900, a shallow-dug well on the Tinney tract, making a small amount of oil, and a 16-foot well cased with 2-inch pipe, making gas, attracted the attention of A. C. Hall, an oil operator at Corsicana, who leased the area surrounding the wells. In April, 1901, the American Well and Prospecting Company and Guffey and Galey took over the leases and later in the year started a cable-tool test (the Maybee well?). In 1902 the cable tools were replaced by a rotary, and Lawson and Cleary started a well on an adjacent 45-acre tract. In 1903, the Guffey and Galey well was abandoned at a depth of 800 feet; their leases were taken over by the Texas Company; and small production was established on the Lawson and Cleary 45-acre tract. In 1904–5, the Texas Company and the American Well and Prospecting Company deepened the Guffey and Galey well to a depth of 1,506 feet and finally abandoned it 150 feet into the salt. Shows of oil were had at 350, 700, and 1,040 feet and a show of sulphur at 1,000 feet. Desultory exploitation of

the shallow productive sands has continued to the present time. In 1917, the Empire Gas and Fuel Company started their deep Becker test, which was finally abandoned in 1921. In 1922, the Humble Oil and Refining Company started deep drilling on the southeast flank of the dome; and during the latter part of 1923 and during 1924, the Union Sulphur Company drilled four tests for sulphur and completed one of them as a small oil well.

Palangana was discovered in 1916 by the Empire Gas and Fuel Company, which drilled its Singer No. 1 in 1916–17. The Sinclair Oil and Gas Company then drilled three wells: Schallert Nos. 1 and 2, which went into the salt on the top of the dome, and Gravis No. 1, three miles east of the dome, which encountered only a normal section. In 1919 the National Oil Company drilled into the salt on top of the dome and then moved eastward with a series of wells, until their No. 4 defined the eastern limit of the salt. Late in 1920, E. F. Simms and Company drilled into the salt on the southern part of the top of the dome and then made a location to the south off the salt for their No. 2. In 1922 the Humble Oil and Refining Company took over the Simms leases, completed the No. 2 well, and drilled three additional wells on the southwest flanks. In 1923 Smith *et al.*, drilling a shallow test on top of the dome, discovered considerable sulphur. In 1924, the Texas Gulf Sulphur Company drilled 25 tests and the Union Sulphur Company 3 tests for sulphur.

PHYSIOGRAPHY

Regional Physiography.—The physiographic province in which the salt domes of south Texas occur is designated as the Gulf coastal plain. In south Texas it consists of the coastal prairie, a flat prairie rising gently from the coast to an abandoned shore which, according to Deussen, runs through Beeville and San Diego; a rolling upland which extends inland from this shore line to the Reynosa (Bordas) escarpment; and a lower plain which rises inland to a more indistinct cuesta. The coastal prairie in general is in extreme youth, but near the coast, in the vicinity of Corpus Christi and Kingsville, is broken by deeply re-entrant bays and by considerable dissection. South of Falfurrias there is much minor relief due to wind activity. The coastal prairie is open and grassy near the coast, but elsewhere

in south Texas is covered with a dense growth of mesquite, which, however, has grown within the memory of the older inhabitants. The upland surface consists of rolling hills and wide, shallow valleys with a fairly well-organized system of drainage. On account of the semi-arid climate, the streams are intermittent. The Reynosa (Bordas) escarpment is upheld by the limestones and calcareous conglomerates of the Reynosa formation.

Within the upland, there is a subordinate cuesta formed by a phase of the Reynosa. The scarp of this cuesta comes in from the southwest, and south of Benavides bends eastward to become the south scarp of the Santa Gertrudis Valley. A mile ($1\frac{1}{2}$ km.) east of Noleda, the north valley scarp bends northward to become the cuesta scarp and takes a northwesterly course concave around the Piedras Pintas dome and convex around the Palangana dome. West of the cuesta scarp, the general level of the hilltops is around 400 feet (120 m.), and that of the valley bottoms is 350–375 feet (105–113 m.) above sea-level. The upland level is around 500 feet (150 m.). In the general vicinity of Palangana and Piedras Pintas, this upland is deeply incised by San Diego and Santa Gertrudis creeks and their tributaries.

Physiography of the Domes.—The salt domes of the coastal group, where surface expression is present, have a surface mound which is very nearly the shape of an inverted washbasin, or of such an inverted basin with a depression in the center. In the case of the interior domes, surface expression takes the form of a ring or rings of hogbacks around a central mound or a central depression.

The surficial expression of the Palangana salt dome is a circular ring of low hills surrounding a central circular basin (Fig. 2). The diameter of the floor of the basin is 8,000 feet (2,400 m.). The diameter of the ring of hills, the crests of which rise 50–80 feet (15–24 m.) above floor of the basin, is 15,000 feet (4,500 m.). On the east and the west, the broad, flat-topped hills of this circular rim slope rather quickly down to the level of the western lowlands. On the northwest, north, and east, they are separated from the uplands of the cuesta by an incomplete ring of valleys concentric with themselves and with the central basin. On the northeast, they slope steeply down into the valley of the Taranchua. The floor of the basin is not

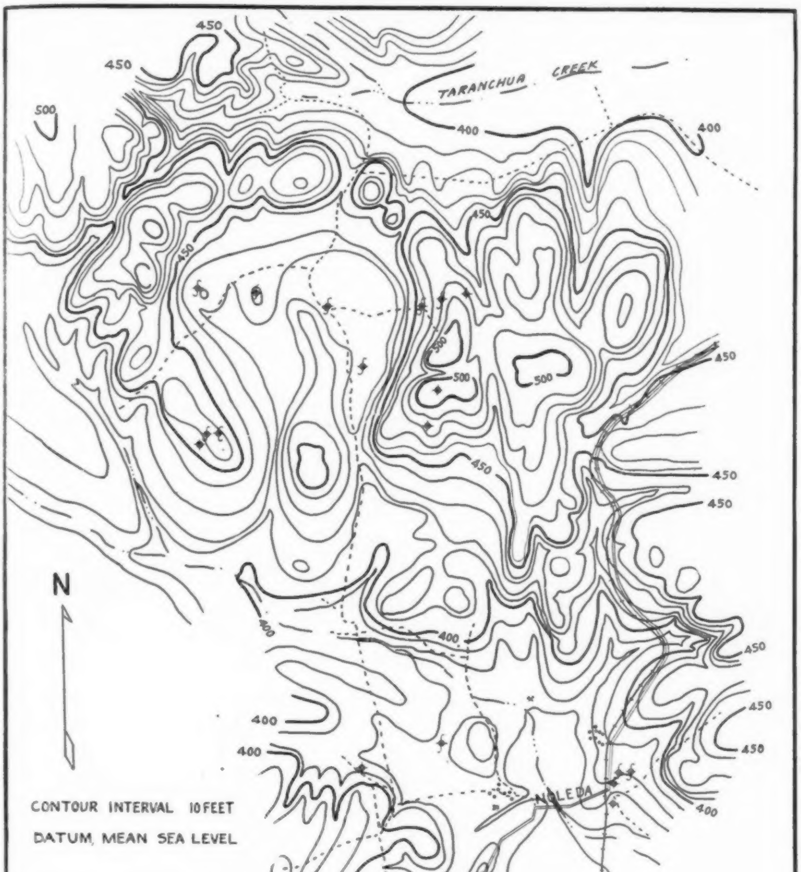

Fig. 2.—Topographic map of Palangana and Piedras Pintas

a simple plain, but is divided on a north-south line through the center by a pair of low, shallow ridges. The basin is drained by a valley which breaches the rim on the southwest and empties into Piedras Pintas Creek.

Three hypotheses can be brought forward to explain the present surficial expression of Palangana: (1) It is the result of the warping of the present general land surface. (2) It is the result of differential erosion of beds already having a domed structure. (3) The central basin is due to collapse of the surface consequent upon the solution of the top of the salt core. This hypothesis is really a modification of either of the two preceding hypotheses.

The evidence favors the second hypothesis in preference to the first. The crest of the hills around the basin are broad and flat-topped, and except where evidently lowered by erosion, rise to the general level of the upland surface to the northwest and the east. From the Empire Gas and Fuel Company's Palangana No. 1 well eastward there is a drop in 6,000 feet (1,800 m.) of only 5 feet (1.5 m.) From the northwest crest northwestward, there is in the same distance no drop, and in a slightly greater distance there is a slight rise. Furthermore, the flat-topped surface of the crests of the rim is separated from the upland surface by valleys which give every evidence of being erosional. This flat-topped surface of the rim seems to be a remnant of the general upland surface. A doming of that surface amounting to 10–15 feet (3–5 m.), or slightly less than the doming of the surface over such salt domes as Hockley and Hull and greater than that over the salt domes at Pierce Junction and North Dayton, might, however, be extremely difficult, if not impossible, of detection on account of the very considerable dissection of this region. As may be seen by reference to Figure 4, the ring of hills owes its existence to the presence of the relatively resistant rock layer which outcrops in them and dips gently away from the dome.

In connection with the third hypothesis, the weight of the evidence would seem to be in favor of the theory of collapse of the underlying beds. In his earlier paper on Palangana, the writer expressed the opinion that "the main evidence against that theory (of collapse) is the absence within most of the basin of the heavy rock like that which caps the rim and is found in the wells on the outer

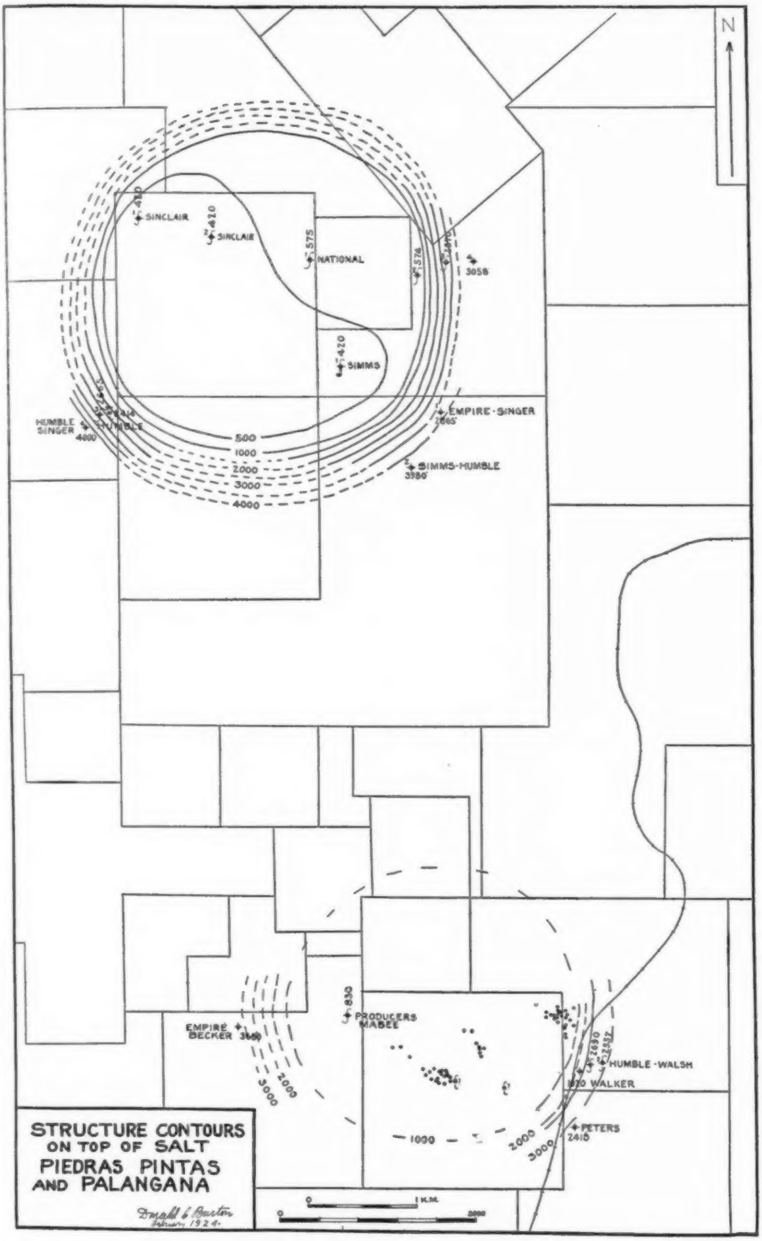

Fig. 3.—Structure and well map of Palangana and Piedras Pintas

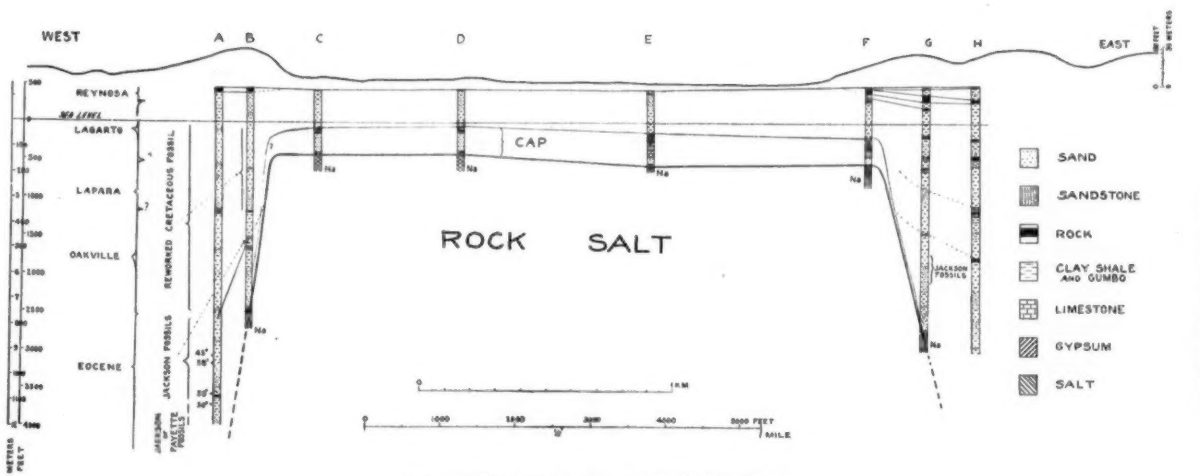

FIG. 4.—West-east Cross-section of Palangana

Scales: vertical = horizontal in geologic section; vertical: horizontal = 5:1 in topographic profile. *A*, Humble Oil and Refining Company's Singer No. 4; *B*, No. 2; *C*, Sinclair Oil and Gas Company's Schallert No. 1; *D*, No. 2; *E*, National Oil Company's Schallert No. 1; *F*, No. 2; *G*, No. 3; *H*, No. 4.

edge of the rim and which should be present within the basin if it were due to collapse." That conclusion was based on the logs of the Sinclair Oil and Gas Company's Schallert wells and of National Oil Company's Schallert No. 1, which are now known to give an erroneous picture of the supersalt beds. Massive rock, probably equivalent to the rock capping the rim, was found in most of the Texas Gulf Sulphur Company tests and is very substantial evidence in favor of the formation of the basin by collapse of the subsurface. At a depth of 265 feet (80 m.) in the National Oil Company's Schallert No. 2, very hard siliceous beds were encountered which were reported to have drilled as if dipping steeply toward the dome. As these siliceous beds are due to secondary silicification, they are not necessarily parallel with stratification and their dip toward the basin does not necessarily indicate a general dip into the basin. As the central basin is well drained through the valley which breaches the southwest quadrant of the rim, erosion by stream activity through that valley also would seem competent to have formed the central basin.

The surface expression of the Piedras Pintas dome is extremely indefinite. Piedras Pintas Creek flows across the center of the dome. Over the probable area of the salt, the shallow valley of Piedras Pintas Creek widens to a broad flat, which is roughly circular in outline and is bounded on the east by the hills east of the railroad at Noleda, on the south by the hills south of Noleda village, on the west by the hills near the Empire Gas and Fuel Company's Becker well, and on the north by a low, short ridge about one-third of the way from Noleda village to Palangana. The flat is broken by a low ridge due in large part at least to the presence of a siliceous knob at the surface. The outline of the salt is not known, and therefore the relation of this indistinct basin to the dome is not determinable. As the Humble Oil and Refining Company's Walsh Nos. 1 and 2 seem probably to be on the east edge of the salt, the west slope of the hills east of the railroad at Noleda seems to mark roughly the east edge of the salt. On the west, the Empire Gas and Fuel Company's Becker No. 1 is off the salt, and is back from the eastern slope of the hills near it. This flat is very much larger than the roughly circular small flat basins which are found here and there along most of the creeks of this region, and furthermore, it is of about the same area as the cen-

tral basin at Palangana. Probably this Noleda flat is the surficial expression of the Piedras Pintas salt dome, but if the salt dome were not known to be present, the topography would hardly lead one to suspect the presence of a dome.

GEOLOGY

Surface Geology.—The Reynosa formation is the characteristic surface formation of the general area around Palangana and Piedras Pintas. It is unconformably overlain by the Lissie gravels (Equus beds), and locally the Lagarto formation is exposed lying unconformably beneath it. The Reynosa is a heterogeneous formation composed of a conglomerate of pebbles of different materials in a calcareous matrix, uncemented gravels, clays, limy sands and sandstones, and tufaceous limestone grading into clays and sands. The Lagarto formation consists of sands and clays which change locally to calcareous sand rock and siliceous or calcareous conglomerate. The Lagarto formation is underlain by the Lapara formation, which consists of interbedded sands and clays carrying porcellanous and flintlike quartzitic material.

At Palangana the crest of the rim is capped by the Reynosa limestone, which also forms all of the hills back of the rim. In Taranchua Creek, Dumble found some sands underlying the Reynosa which seemed to belong to the Lagarto. The rock of the rim has been found within the central basin only in the Simms well at the southern end, where it composed the upper 150 feet of the section. Elsewhere in the central basin, the surface and the upper part of the section in the wells is sand, the age of which is not known; it may belong to the Lagarto or may be part of an older formation which has been brought up by the salt.

At Piedras Pintas, the hills surrounding the Noleda flat are composed of Reynosa limestone. The Noleda flat is covered by a veneer of alluvium. Underlying it is a series of sands and siliceous rocks which outcrop at the base of the surrounding hills, in the knob within the basin, and in the quarries. The name Piedras Pintas, meaning, "Painted Rocks," comes from a group of silceous rocks covering an area of about 200 square yards (167 sq. m.) and situated 2,000 feet (600 m.) west-southwest of Noleda village. The rocks are a series of

coarse and fine sands and of thin shale bands which have undergone varying degrees of silicification. Much of the fine-grained rock is very dense, and looks like a chert. The finest-grained layers are porcelaneous. Many of these are brecciated into sharp, angular, and in some cases splintery fragments, and therefore seem to have acquired their brittleness before the brecciation; but as the cracks between the fragments are filled with coarse sand grains from the overlying or underlying sand beds, the brecciation must have taken place before the silicification of the sands.

A quarry opened to obtain riprap for use at Corpus Christi, is located in the northeast central portion of the Noleda flat, northeast of the central siliceous knob. The quarry is 100 feet (30 m.) long by 40 feet (12 m.) deep. The main bed of siliceous rock is irregular, but averages some 20 feet (6 m.) in thickness. Showing a dip of 30° to 40°, it forms most of the west wall and part of the east wall of the quarry. Above the silicified rock are irregularly bedded sands of varying coarseness and of varying degrees of cementation. Intercalated in the sands are small masses of altered clays which are chalky white, unctuous, impalpible, faintly bitter, and without argillaceous odor. The siliceous rock shows contorted bedding, but varies greatly in character. In some of its phases, it is a quartzitic siliceous sandstone; some very fine-grained material resembles novaculite; other phases are like buhrstone; locally it is chalcedonic. In only one case were the walls of the channels incrusted.

Similar siliceous rock is found in the central knob and in isolated small patches elsewhere around the edges of the Noleda flat. Near the Peters well just south of the Noleda railroad crossing, thin beds of porcelaneous siliceous rock are interbedded in unconsolidated sands. Flinty, quartzitic rock similar to the siliceous rock at Piedras Pintas was found at 60 and 265 feet (18 and 81 m.) in the National Oil Company's No. 2, at Palangana.

The siliceous rocks are due to the deposition in sediments already present of silica from siliceous waters. But the silicification has not taken place recently and seems to have been accomplished before the beds were in their present position. Siliceous knobs occur at several places in the region west of Palangana and Piedras Pintas. Porcelaneous and flintlike quartzitic material is described by

Dumble as occurring in the Lapara. Although the association of the silicified rocks with the salt dome may be suggestive of the genetic association of the hydromineralization with the salt dome, there is no evidence to that effect, and the most probable explanation is that siliceous beds in the Lapara or other formation were uplifted to the surface by the salt.

Subsurface Geology.—Structurally the American salt domes consist of a stocklike core of rock salt with or without a cap of rock, and of beds dipping steeply and quaquaversally from the salt core. The salt core is circular or broadly elliptical in plan, with a diameter of anywhere from $\frac{1}{2}$ to $3\frac{1}{2}$ miles (1 to 5.5 km.); it has nearly vertical sides and a relatively flat top. The cap rock is disklike or thimble-like in form and is composed of anhydrite, gypsum, or limestone, or of all three. Commonly there is a little limestone lying on top of a larger mass of anhydrite-gypsum. The thickness of the cap ranges up to 1,000 feet (300 m.). The dip of the beds on the flanks of the dome varies with the dome, with the depth of the bed, and with the distance from the salt. Dips of more than 45° are common on the deeper beds.

Palangana has the characteristic structure of an American salt dome. The salt core is approximately circular in outline, with a diameter of 11,000 feet (3,300 m.), and has a flat top and very steep flanks. A cap of rock is present which covers the top of the dome and extends well down the flanks. On the flanks of the dome, the lateral sediments dip steeply away from the salt core.

The salt core is delimited on the east by the National Oil Company's wells Nos. 2, 3, and 4, which, respectively, hit the salt at 1,019 feet (310 m.) and 3,347 feet (1,017 m.), and went to below 3,350 feet (1,018 m.) without finding the salt. On the southwest the Humble Oil and Refining Company's wells Singer No. 5 hit the cap rock at 1,951 feet (593 m.); No. 3, cap rock at 2,954 feet (898 m.) and salt at 3,104 feet (944 m.); and No. 4, no cap rock or salt to 4,440 feet (1,350 m.). On the south and southeast Simm's Singer Nos. 1 and 2 and the Empire Gas and Fuel Company's Singer No. 1, respectively, hit salt at 836 feet (254 m.), found no salt or cap rock to 4,407 feet (1,340 m.), and failed to find either salt or cap rock at 3,000 feet (912 m.). On the northwest the Sinclair Oil and Gas Company's

Schallert No. 1 hit the salt at 985 feet (299 m.).[1] From the position of these wells and from the structure contours on the salt in them (Fig. 3), the salt core is proved to be roughly circular in outline and to have a diameter at the top of 11,000 feet (3,350 m.). From the symmetry of the topography, also, the outline of the salt core seems to be circular. The top of the salt is flat; the depths at which it was encountered are 420 feet (128 m.), 420 feet (128 m.), 575 feet (175 m.), 574 feet (174 m.), and 420 feet (128 m.) below sea-level respectively in various wells. The flanks of the salt core are steep; on the east the slope of the salt between the National Oil Company's Nos. 2 and 3 is more than 70°; on the southwest, the slope of the salt between the Humble Oil and Refining Company's Singer Nos. 5 and 3 is probably slightly less than this; but between Nos. 3 and 4, it is more.

The cap was reported in the writer's previous paper on Palangana[2] to be poorly developed. That statement was based on the data then available from the drillers' logs of the Sinclair Oil and Gas Company's Singer Nos. 1 and 2, and the National Oil Company's No. 1, and in the light of information now available seems to have been in error. In Simm's Singer No. 1, the cap was encountered at a depth of 27 feet (8 m.), above sea-level, and 488 feet (148 m.) of solid rock was found. The Humble Oil and Refining Company's Singer No. 5 had over 249 feet (75 m.) of anhydrite, and No. 3 had 150 feet (46 m.) of anhydrite. The National Oil Company's No. 3 had 50 feet (15 m.) of anhydrite above the salt. The four wells, Sinclair Oil and Gas Company's Schallert Nos. 1 and 2, and National Oil Company's Schallert Nos. 1 and 2, logged a thick bed of "lime and gyp" respectively at 60, 60, 145, and 127 feet (18, 18, 44, and 39 m.) below sea-level, and then a series of sand, "rock," "gyp," and "lime," to the salt. In the National Oil Company's Schallert No. 3, cores showed definitely that the drillers' "sand" and "crystallized sand" were anhydrite. As anhydrite is seldom recognized by the Gulf

[1] The Texas Gulf Sulphur Company's No. 6, situated 2,000 feet (600 m.) north-northwest of the Sinclair Oil and Gas Company's Schallert No. 1, encountered no cap rock and went directly into the salt at a depth of 1,037 feet, and No. 11, situated 3,600 feet (1,100 m.) north-northeast of the National Oil Company's No. 2, went to a depth of 732 feet (223 m.) without encountering cap rock or salt.

[2] This *Bulletin*, Vol. 5, p. 219; *Econ. Geol.*, Vol. 6 (1920), pp. 497-510.

coast driller, but is indiscriminately logged as "crystallized sand," "hard sand," "lime," or "gyp," the writer suspects that there is a thick cap of anhydrite which was not recognized by the drillers on the Sinclair wells and the National wells Nos. 1 and 2. If this is so, there is a cap which extends completely over the top of the dome as well as down the flanks, and has the following thicknesses: on top of the dome, Sinclair Oil and Gas Company's Schallert Nos. 1 and 2, 362 feet (110 m.); National Oil Company's No. 1, 425 feet (129 m.); No. 2, 435 feet (132 m.); Simm's No. 1, 448 feet (136 m.); on the east flank, 50 feet (15 m.) at a depth of 3,300 feet (1,000 m.); on the west flank, 248 feet (75 m.) at 1,900 feet (578 m.) in the Humble Oil and Refining Company's No. 5; and 150 feet (46 m.) at 2,950 feet (897 m.) in No. 3.

The character of the cap on the top of the dome is known well now as the result of the exploration for sulphur. The section through the cap is shown in Table I. The top of the cap is vague and irregular, and according to Mr. Wolff, of the Texas Gulf Sulphur

TABLE I

GENERALIZED SECTION THROUGH THE CAP, PALANGANA

	Feet	Meters
Limestone, calcite, clay, and shale..........	520	1.5-6
Limestone, calcite, clay, shale, and sulphur..	3-25	1 -8
Gypsum, at the top a little clay and shale...	100+	30 +
Anhydrite..............................	300—	90 —

Company, the upper part of the cap seems to be composed of a mechanical mixture of clay and shale with blocks of the "lime" cap rock and of clay and shale in fissures and caverns in the "lime" cap rock. The only specimen of the "lime" cap rock seen by the writer was composed of oil-soaked medium-grained granular limestone cut by many fissures partially filled by vein calcite (dolomite?). Much of the sulphur is found in the clay and shale and is regarded by Mr. Wolff as residual material left from the solution of the limestone. The gypsum is of the characteristic salt-dome cap-rock type, but showed more evidence of shearing than the writer has seen previously in Gulf Coast cap rock. The anhydrite was not reached in the Texas Gulf Sulphur Company tests and the exact thickness of the

gypsum zone is not known. The top of the cap, as nearly as it can be determined, is relatively flat; between the National Oil Company's No. 1 and the northeast edge of the dome, it rises to an elevation of about 100 feet (30 m.) above sea-level and from that area slopes down to an elevation of about 50 feet (15 m.) below sea-level not far in from the edge of the salt on the north and west, and to an elevation of several hundred feet below sea-level in a comparable position in reference to the southwest edge of the salt. The absence of cap rock in the Union Sulphur Company's No. 6 indicates that the cap does not extend continuously down the northwest flank of the salt core; and the presence of the cap in the Humble Oil and Refining Company's Singer Nos. 3, 5, 6, and 7 indicates that the cap extends down the southwest flank of the dome to a depth of at least 3,100 feet (940 m.).

On account of the uncertainty of drillers' identifications, the lithologic character of the cap on top of the dome is not known. On the southwest flank, the section through the cap in the Humble Oil and Refining Company's Singer Nos. 2 and 5 is as shown in Table I. The anhydrite is a fine-grained, dense, hard, deep-blue, well-crystallized rock, characteristic of Gulf Coast salt-dome cap rock. The anhydrite of a core with several solution channels is white. As the cap is relatively thin but steeply dipping, and as only slight lateral movement would be necessary to fault or fold in lateral sediments, the calcareous sandstone logged at 3,005, 3,021, and 3,063 feet (914, 918, 931 m.) does not necessarily belong in the cap-rock mass. The black clay at 3,104 feet (944 m.) is less like the abutting lateral sands, and there is more probability that it is actually included in the cap-rock mass. On the east flank, the cap rock in the National Oil Company's No. 3 is a much more coarsely crystalline, saccharoidal anhydrite. That well went through 130 feet (39.5 m.) of salt and encountered 15 feet (4.5 m.) of similar anhydrite underlain by hard sand, in which the well was abandoned. Sulphur has recently been encountered in considerable quantity in Smith *et al.*, Schallert No. 1 at 390 feet (119 m.).

The steepness with which the lateral sediments dip away from the salt core is distinctly shown in the Humble Oil and Refining Company's wells on the southwest edge of the dome. The con-

tact between the Jackson and the Miocene in their Nos. 3, 4, and 5 was found respectively at 1,228–1,447 feet (373–440 m.), 1,660–2,017 feet (505–613 m.), and 2,950–3,041 feet (897–924 m.). The first number in each case gives the depth of the last sample which

TABLE II

Cored Section through the Cap

Depth, Feet	Depth, Meters	Composition of Core
Humble Oil and Refining Company's Singer No. 2		
1,957	595	Galenite with sphalerite and possibly smithsonite veining.
1,959	596	Calcite and a few crystals of anhydrite with smithsonite in veins and cavities.
1,962	597	Calcite, 50 per cent; anhydrite, 50 per cent.
1,968, 1,972, 1,977, 1,982	598	Anhydrite.
1,988	604	Anhydrite with dip of 55°.
1,994, 1,995, 1,998 2,000, 2,003, 2,005 2,010, 2,018, 2,019 2,029, 2,035, 2,063 2,077, 2,080, 2,096 2,108, 2,121	606–45	Anhydrite.
Humble Oil and Refining Company's Singer No. 5		
2,984	907	Calcareous, hard sandy clay.
2,986	908	Anhydrite.
3,005	914	Highly calcareous sandy clay.
3,005	914	Anhydrite.
3,021	918	Calcareous sandstones.
3,021	918	Fine-grained dolomitic limestone.
3,040, 3,049, 3,055, 3,061	924–30	Anhydrite.
3,063, 3,068	931–33	Calcareous sandstone with impressions of shells of *Leda*? and *Lucina*.
3,063, 3,084	931–38	Anhydrite.
3,104	944	Black calcareous clay with crystals of salt and anhydrite; fragments of oyster shells replaced by salt.
3,158	960	Anhydrite.
3,180	967	Salt.

could be recognized as Miocene, and the second number the depth of the first sample which could be recognized as Jackson. Cores taken in No. 4 had the following dips: 45° at 3,538 feet (1,076 m.), 58° at 3,588 feet (1,091 m.), 50° at 4,021 feet (1,193 m.), 30° at 4,197 feet (1,245 m.), and 30° at 4,222 feet (1,283 m.).

On account of the small number of wells that have been drilled on the flanks, the detailed structure of the lateral beds around the salt core cannot be worked out.

Piedras Pintas is a known salt dome and probably has the characteristic form and structure of an American salt dome. The top of the salt lies at a depth of about 1,350 feet (410 m.) below sea-level, but as only one well, the Producers' Oil Company's Mabee well, is known to have been drilled into the top of the salt, its form is not known. Positive control is given on the east by the Humble Oil and Refining Company's Walsh wells Nos. 1 and 2, which found the salt respectively at 2,690 feet (818 m.), and 2,557 feet (777 m.) below sea-level and which, therefore, must be on the east side of the salt. Negative control is given on the southeast by the Peters well, which found no salt or cap to a depth of 2,917 feet (887 m.) below sea-level, and on the west by the Empire Gas and Fuel Company's Becker well, which found no salt or cap to a depth of 3,618 feet (1,100 m.). below the surface. The dip of the flank of the salt core is not known. In the Humble's Walsh wells, there is a slight irregularity in the flank of the salt, as the outer well (No. 2) found the salt 122 feet (37 m.) higher than No. 1.

A cap is present on top of the dome at Piedras Pintas. The four Union Sulphur Company tests for sulphur were located as follows: (see Fig. 3) Tinney No. 1 at the west edge of the southwest group of shallow wells, Saenz No. 1 at the west edge of the central group of wells, Tinney No. 2 east of No. 1 and south of Saenz No. 1, and Canales No. 1 just east of the well with a "C" through the symbol. The log of Tinney No. 1 shows gypsum from 556 to 562 feet and "calcite and lime" from 585 to 625 feet; the log of No. 2, calcareous sandstone, limestone, and shale from 269 to 410 feet, sandy limestone from 410 to 599 feet, gumbo (stiff clay), sandstone, and "lime" from 599 to 1,020 feet, and limestone and gypsum from 1,021 to 1,035 feet; the log of Saenz No. 1, "lime and calcite" from 387 to 619 feet and anhydrite from 619 to 687 feet. Canales No. 1 went to a total depth of 1,028 without encountering any considerable quantity of rock. Much of the "lime," limestone, and sandstone is the result of secondary calcareous cementation and impregnation of previously existing sediments. How much of it, if any, is true "lime" cap rock is impossible to say. None of the few samples seen by the writer were

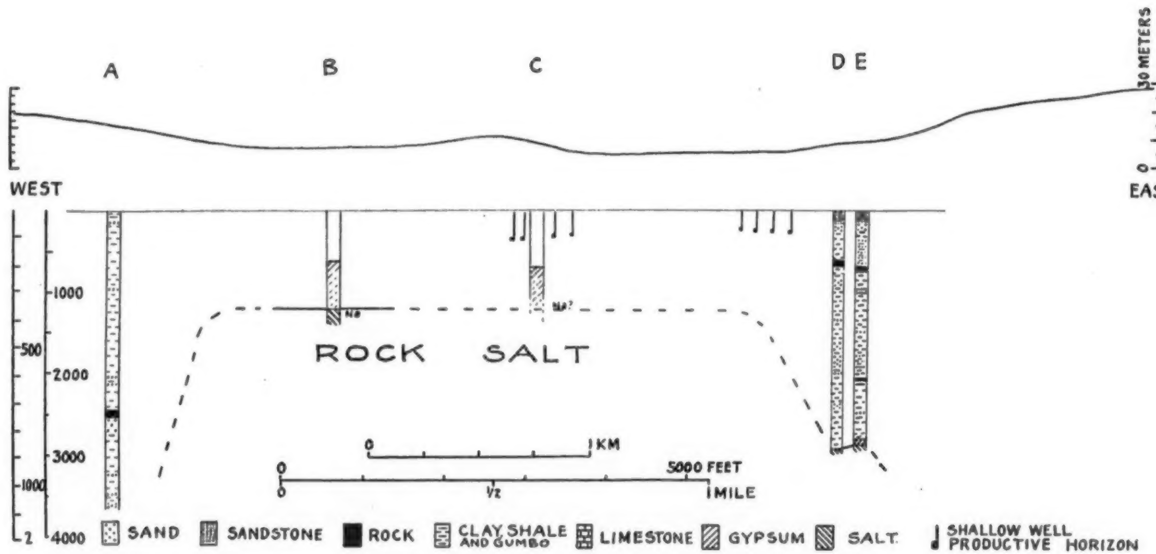

FIG. 5.—West-east cross-section of Piedras Pintas dome

Scales: section, vertical = horizontal; profile, vertical: horizontal = 10:1. *A*, Empire Gas and Fuel Company's Becker No. 1; *B*, Producers Oil Company's Maybee No. 1; *C*, Lawton well; *D*, Humble Oil and Refining Company's Walsh No. 1; *E*, Walsh No. 2.

cap rock. The anhydrite is part of the true cap. Its position so much higher in the Saenz No. 1 than in the Tinney No. 2 and the Canales No. 1 and possibly the absence of rock in the Canales well probably indicates very irregular uplift on the top of the dome. The absence in the Canales well of the masses of "lime" rock found in the other wells may be attributable, however, to differences in the conditions of deposition of the secondary calcite. It is possible that the uncommon amount of calcareous cementation in the deeper supersalt beds is genetically connected with the uncommon amount of siliceous cementation in the beds at and near the surface. These data regarding the situation above the top of the salt are vague and unsatisfactory; the correct interpretation of the situation will have to wait on the drilling of a very considerable number of wells through the cap rock.

On the flank in the Humble Oil and Refining Company's Walsh No. 1, no cap rock was found, and in No. 2, only ten feet of anhydrite.

Nothing is known regarding the structure of the lateral beds. In Walsh No. 1, a core at 2,353 feet (925 m.) showed bedding with a dip of 45°, and in Walsh No. 2 a core at 1,782 feet (752 m.) showed a dip of 35°.

Stratigraphy.—The normal stratigraphic section for the region southwest of Brazos River is given in Table III. The section at Palangana as indicated by some of the wells is given in Table IV. At Piedras Pintas, the section as determined by micro-paleontological analysis is as shown in Table V.

The section at Palangana and Piedras Pintas shows great thickening over the normal section for south Texas. As the wells Singer Nos. 3 and 5 and Walsh Nos. 1 and 2 are on the side of the salt, and as Singer No. 4 is very close to the edge of the salt, the beds in them have experienced great uplift. The relative uplift in Singer No. 3 over Singer No. 4 on the reworked Cretaceous-Miocene contact is 700–1,000 feet (210–300 m.), and in Singer No. 5 over Singer No. 4 is 1,570–1,870 feet (498–589 m.). At higher horizons, the uplift is less; on what is tentatively classed as the top of the Oakville, the relative uplift of No. 3 over No. 4 is of the order of 150 feet (45 m.). The absolute uplift cannot be determined from these wells. As the

result of the uplift, the section in the wells must have been shortened either through depositional thinning of the beds, thinning by squeezing, faulting out of beds, or erosion. Singer No. 4, being the farthest out from the salt, should have a section nearest the normal, but in spite of the fact that it must have experienced much shortening, the

TABLE III

NORMAL STRATIGRAPHIC SECTION

Formations	Description	Thickness	
		Feet	Meters
Pleistocene Beaumont clay..............	Blue calcareous clay with small lime nodules and with lenses of sand and sandy clay.	300– 900	90–270
Lissie gravel................	Gravels and coarse sands with pockets of red clay; limy conglomerate south of Guadalupe River.	500–1,000	150–300
Unconformity Pliocene(?) Reynosa formation..........	Calcareous conglomerates and limestones with lenses of pink clay.	560–1,500	170–450
Unconformity Pliocene Lagarto clay................	Clays light colored, mottled, with limestone nodules and with sands and sandstones.	345– 645	105–195
Lapara sand................	Interbedded sands and clays with clay pebbles and limestone concretions.	75– 455	23–138
Unconformity(?) Miocene Oakville sandstone..........	Gray sandstone, soft and hard, calcareous and non-calcareous, with some clay lenses.	180– 600	55–180
Unconformity Oligocene Catahoula sandstone.........	Quartzitic sandstones, clays, sandy clays, and sandstones.	0–1,200	0–360
Oligocene in part (?) Eocene, Jackson in part (?).....	Clays, marls, limestone, concretions, beds of volcanic ash.	235– 700	70–210
Eocene Jackson (?) Fayette sandstone...........	Sands, sandstones, clays, lignite, volcanic ash	480– 800	145–240
Claiborne Yegua.....................	Clays, lignite clays, lignite, oyster reefs.	475–1,050	143–315
Cook Mountain.............	Greensand, greensand marls, iron ore, lignite, clay, sand, and sandstone.	520– 865	155–260

section to the top of the Jackson here shows great thickening. On the basis of lithology, the thickness of the Reynosa in this well is less than 100 feet (30 m.); on the basis of fossils, there is a 90-foot barren zone which is Miocene, Oligocene, or Jackson. If the barren zone is assumed to be Oligocene, and if the maximum thickness of the Lagarto, Lapara, and Oakville are taken, the top of the Jackson

TABLE IV

STRATIGRAPHIC SECTION AT PALANGANA

Depth		Formation
Feet	Meters	
Singer No. 4		
Surface	Surface	Reynosa
470–2,950	143– 910	Reworked cretaceous
2,955–3,013	912– 919	Non-fossiliferous cores
3,041–4,187	928–1,277	Jackson
4,274–4,440	1,303–1,354	Jackson or Fayette
Singer No. 3		
Surface	Surface	Reynosa
520–1,660	158– 506	Reworked cretaceous
1,660–2,017	506– 615	No cores
2,017	615	Jackson
Singer No. 5		
Surface	Surface	Reynosa
–1,284	– 392	Reworked cretaceous
1,346	410	Non-fossiliferous core
1,447–1,959	441– 597	Jackson

TABLE V

STRATIGRAPHIC SECTION AT PIEDRAS PINTAS

Depth		Formation
Feet	Meters	
Walsh No. 1		
Surface	Surface	Reynosa
616– 854	188–260	Reworked Cretaceous
855–2,745	261–837	81 cores taken barren of fossils
2,746–2,872	838–876	Upper Claiborne
Walsh No. 2		
Surface	Surface	Reynosa
151– 990	46–307	Reworked Cretaceous
990–2,817	307–859	Many cores barren of fossils
2,817–?	859–?	Upper Claiborne

should come at a depth of 1,900 feet (599 m.). It actually comes at 3,041 feet (924 m.). The section above the Jackson shows, therefore, a thickening of 1,150 feet (350 m.), or over 50 per cent. This thickening of the section in the wells over the old "normal" section determined from studies of the formations at their outcrops is characteristic of the Gulf Coast. The actual thickening of the section at Palangana must be very much more than that shown in Singer No. 4, and the actually demonstrated thickening at many places in the Gulf Coast, as, for example, Pine Prairie and Orange, is over 2,000 feet (600 m.). Thickening of the section seaward is, of course, expected, but before the detailed work of the oil geologists in the past three years, the enormous degree of thickening was not suspected. This demonstration of the unexpectedly great thickening of the section shows the danger in extrapolating down the dip seaward, the knowledge gained at the outcrop, and this warning is particularly pertinent in the Palangana–Piedras Pintas region. In his recent studies of the section along the Rio Grande, Trowbridge found no Oakville, Lapara, or Lagarto at the outcrop, and although he mentions the presence of Miocene sediments in the Brownville region, 120 miles (190 km.) south of Palangana–Piedras, and says that the outcrop of the three formations may be hidden under the overlap of the Reynosa, yet the impression given by his discussions warrants no suspicion of over 2,000 feet of Oakville, Lapara, and Lagarto at Palangana–Piedras Pintas, only 30 miles (48 km.) back from the outcrop.

The tentative differentiation of the section above the Jackson is as follows:

The Reynosa formation, on the basis of the reported lithology, is about 55 feet (17 m.) thick in the Humble Oil and Refining Company's Singer Nos. 3, 4, and 5 (Fig. 4); in the National Oil Comany's Nos. 3 and 4, it is 40 or 250 feet (12 or 75 m.) thick. The surface rock is Reynosa. The deeper massive rock may be Reynosa or may be a mineralized bed in the Lagarto.

Below the Reynosa, the predominating clayey zone, 850 feet (258 m.) thick in the Humble Oil and Refining Company's Singer No. 4, and 600–650 feet (180–200 m.) thick in the National Oil Company's Nos. 3 and 4, is referred tentatively to the Lagarto.

Below the tentative Lagarto, there is a zone with sand and sand-

stones in the upper part, and clay in the lower part. In the Humble Oil and Refining Company's No. 4 it is 725 feet (220 m.) thick, and in the National Oil Company's No. 4 it is 500 feet (150 m.) thick. It is tentatively referred to the Lapara.

At 1,600 feet (480 m.) in the Humble Oil and Refining Company's No. 4 and National Oil Company's No. 4, there are several hundred feet of sand, sandstone, and limestone (?). The upper part, composed of alternating clays and gumbos, may belong to the Lapara. The lower part is tentatively referred to the Oakville. The 1,000 feet (300 m.) of clays, sands, and sandy clays below these sands, sandstone, and rock and above the base of the "reworked Cretaceous zone" is referred to the Oakville.

In the Singer No. 4, between the lowermost core which was identified as Miocene and the uppermost core which was identified as Jackson there is a zone 90 feet (27 m.) which was unfossiliferous, and which might be Oligocene. Although well developed in Southeast Texas, the Oligocene wedges out in the outcrop south of the Brazos and is not found at the surface in south Texas, and Oligocene fossils have not been recognized in any of the wells in south Texas. It is very possible, therefore, that Oligocene is missing at Palangana–Piedras Pintas. If present, it can not be over 90 feet (27 m.) thick in Singer No. 4.

A curious feature of the relative stratigraphy of the different wells is that Singer No. 4 had reworked Cretaceous Foraminifera from 470 to 2,950 feet (141 to 900 m.), and that Singer No. 2 and Walsh Nos. 1 and 2 had no reworked Cretaceous Foraminifera below around 1,000 feet (300 m.). As in Walsh No. 1 some eighty-one cores were taken in the barren zone between 855 feet (281 m.) and the top of the Jackson at 2,746 feet (856 m.), there would seem to be no doubt of the absence of the reworked Cretaceous fossils. In the same zone in Singer No. 4, reworked Cretaceous fossils were present in nineteen cores. Just what the significance of their absence may be, is not known. The situation of Singer No. 4 west of the axis of the two domes and the situation of Singer No. 2 and Walsh Nos. 1 and 2 east of the axis suggests that during the Miocene and early Pliocene, the two salt domes had sufficient surface expressions in some way to affect the processes of deposition.

AGE OF THE DOMES

The age of the salt is not known definitely. As it pierces formations as old as Upper Claiborne, it must be older than Upper Claiborne. As, in the interior group of Texas salt domes, it has brought Austin chalk to the surface, the salt there must be at least as old as earlier Upper Cretaceous. As none of the known formations of the early Tertiary or of the Upper Cretaceous has a facies compatible with the formation of salt deposits, the salt of the Gulf Coast domes is probably at least as old as Lower Cretaceous.

The age of the upthrust of the salt is middle Miocene or earlier to late Pliocene or Plio-Pleistocene. The date of the beginning of the upthrust is not determinable As the beds down to a depth of 1,500 feet (457 m.) in Singer Nos. 3 and 4 have only a moderate dip and so do not conform to the steep dip of the top of the Jackson, a part of the upthrust must have taken place at the end, or in the latter part, of the Jackson; and as the Miocene-Jackson contact has been tilted into a dip of some 50° a part of the upthrust must have come since the beginning of the Miocene. As it is impossible to correlate with enough accuracy to determine the amount of the angular unconformity which occurs in or at the end of the Miocene, it is impossible to determine how much upwarping there had been before the early Miocene. The earliest dated upthrust that the writer has observed is at Damon Mound. There an angular unconformity of 15° to 20° between the Oligocene and the Miocene extends out at least $\frac{1}{2}$ mile from the edge of the dome and shows that by the end of Oligocene times there had been greater deformation at the surface than is shown today in any of the Gulf Coast salt domes, and at least as great as is shown at the surface at present by the Palestine and West Point domes. As the amount of uplift which must have taken place by the end of Oligocene is so large, it seems reasonable to suppose that upthrust must have gone well back into the Eocene. The common supposition is that all the salt domes started at about the same time on account of some prevailing condition of tectonic stress. On the basis of this supposition, the beginning of the upthrust would date at least as far back as Eocene times. Although the odds are probably in favor of this supposition, there seems to be no a priori reason why some domes should not have started to form later than

others. Whether or not some particular condition of stress was necessary to start the formation of the domes, the forces necessary to the continuation of the upthrust of the domes have continued to the present, and since in some domes, for example North Dayton, there has been no upthrust later than early Pleistocene, and in others, such as Avery's Island, the upthrust probably is continuing today, the forces causing the upthrust seem not to have affected all domes alike. It is entirely possible that in some places there is a slower accumulation than elsewhere of the stresses which result in the upthrust of the salt, and that in those places the formation of the salt domes starts later than elsewhere.

Although the larger part of the upthrust seems to have taken place in Oakville times, the warping of the Lapara, Lagarto, and basal Reynosa indicates that the upthrust persisted into Reynosa times. Notwithstanding uncertainty of correlation, a slightly greater dip in the Lapara and Lagarto indicates that there was movement during Pliocene times. As the present surface shows no appreciable deformation, there has been no determinable uplift since the early Pleistocene or late Pliocene.

ORIGIN OF THE SALT DOME

General statement.—Although in the geological literature in English, the origin of salt domes is still a much-disputed question, the data now available in regard to the German salt domes show with a high degree of scientific certainty that the German domes are the result of plastic yielding to deformation of a sedimentary salt series, and the comparison of these data with those now available for the American, Mexican, and Roumanian salt domes shows that the different types of salt domes are merely the different manifestations which a single general type of structure takes under respectively different regional tectonic conditions.

Origin of the German salt domes.—The proof of the formation of the German salt domes by the plastic flowage of a sedimentary salt series is based on the following evidence:

1) The German Zechstein salt deposits occur in the following structural types: (*a*) Sedimentary beds showing the effects of only slight deformation; (*b*) Stassfurt type salt-dome ridge: low, broad

anticlines with a low, broad salt core tapering gently to each side and with the overlying sedimentary beds gently arched concordantly with the top of the salt (Fig. 6*a*); (*c*) Asse type salt-dome ridge: a narrow, sharp, anticlinal ridge with a narrow, steep-sided, sharply upthrust core of salt and overlying sedimentary beds sharply arched concordantly with the upper surface of the salt (Fig. 6*b*); (*d*) Lower Aller type salt-dome ridge: an anticline with a salt core that projects into or through the overlying sedimentary beds and is in diapir relations to them; the cross-section is the same as the section of a salt stock; (*e*) Hannoverian type salt stock: a circular or elliptical dome with a core of salt which has been intruded into or through the overlying sedimentary beds (Fig. 6*c*).

TABLE VI

STRATIGRAPHIC SECTION IN GERMAN SALT SERIES

Formation	Thickness
"Younger" rock salt	100 feet (30 m.)
"Pegmatic" anhydrite	3 feet (1 m.)
"Red" salt clay	33 feet (10 m.)
"Younger" rock salt	165 feet (50 m.)
"Main" anhydrite	130 feet (40 m.)
"Gray" salt clay	23 feet (7 m.)
"Older" potash series	130 feet (40 m.)
"Older" rock salt	825 feet (250 m.)

2) The section shown in Table VI (after Seidl), with slight variations in character and thickness, can be recognized not only in the essentially undeformed sedimentary beds, but also in all of the different types of the salt domes. The different salt members have different lithologic aspects and can be distinguished. The "Gray" salt clay in places carries a dwarf marine fauna.

3) The different types grade into each other and are manifestly the different reactions of the Zechstein salt series to variations in tectonic conditions. In the Magdeburg-Halberstadt Basin, which lies as if crushed between the Flechtinger-Hohenzüg and the Harz pre-Permian massifs, the salt domes take the form of ridges with the same Hercynian strike that characterizes the two massifs. In the North German plain across the northwest end of the basin and the two massifs, the structure of the South Hannover district reflects a

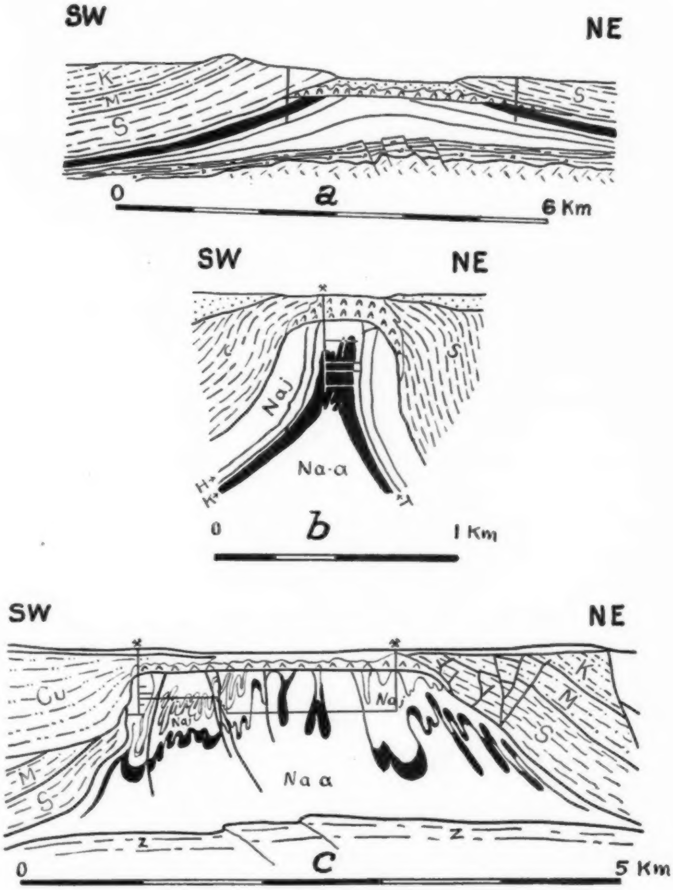

FIG. 6.—Types of German salt domes

a) "Stassfurt" type salt dome ridge, cross-section of the Schmücke-Finne Ridge, after Schlafke.

b) "Asse" type salt dome ridge, cross-section of the Stassfurt Ridge at Wester-Egeln, after Schünemann.

c) "Hannoverian" or "Stock" type of salt dome, cross-section of the Benthe tock, after Stille and Seidl.

Cu = Lower Cretaceous
K = Keuper
M = Muschelkalk
S = Buntsandstein
Naj = "Younger" salt series
Naa = "Older salt series
Λ = Gypsum cap

Rhenish influence, and in that district the salt domes take the form of salt stocks at the intersections of Hercynian and Rhenish anticlinal axes. In northwestward continuation of the Harz and in the Lower Aller district, the Rhenish influence is not so strongly manifest, and the salt domes tend to take the form of salt-dome ridges striking with the Hercynian axes. Farther north in the North German plain, the salt domes take the form of salt stocks. A general law seems to hold in regard to the form of the cross-section, that where the sedimentary cover is relatively thin, as in the Magdeburg-Halberstadt Basin, the Stassfurt and Asse types with the cover concordant with the upper surface of the salt prevail, and that where the cover is thick, the Hannoverian type prevails, with the salt core in diapir relation to the cover.

4) The abundance of exposures in the potash mines with their galleries at many levels, the data from the borings made in exploration for potash, and the differentiation of the salt series into recognizable members has made it possible to work out the structure of some of the domes in great detail and to demonstrate the great plasticity of the salt.

The genetic connection of the American salt domes with the German as a single type of structure is demonstrated through a study of the German salt stocks, especially through such a dome as the Benthe dome. This is an elongated elliptical dome in which the salt core has steep to nearly vertical sides and has been intruded through beds from Permian to Senonian (Lower Cretaceous), inclusive. Buntsandstein and Muschelkalk have been brought to the surface along the edge of the salt and at the surface can be seen dipping steeply away from the salt core; and at one point are even overturned. Except that the major diameter is two and a half times the minor diameter, in contrast to the equal or subequal diameters of the American salt domes, the outer form and structure of the Benthe dome are identical with those of such domes as Keechi, Palestine, and West Point, and the difference between the aspect of these three domes and the domes of the Gulf is merely due to the presence of a thick column of Neogene to Recent Sediments, which are present along the Gulf Coast but not inland. As the salt cores of the American domes are exposed only in the rather small mines at Avery,

Jefferson, and Weeks Islands, the structure has not been determined, but in the Weeks and Avery salt mines, the salt of the American domes exhibits the same plastic folding shown by the salt of the German domes.

The evidence for the formation of salt domes through plastic yielding to deformation is definite and positive. The opposing theories are mostly a priori. They were based on very imperfect knowledge, and are so little applicable to salt domes as they are known today that discussion of them need be entered into only in treating the history of the development of geologic thought in regard to the origin of salt domes.

The recent discovery of mixture of sylvite and halite in a core from 4,800 feet in the Rycade Oil Corporation's Gray No. 1 on the Markham salt dome adds further evidence to the similarity of the American and German salt domes, and the discovery of algae in the salt gives strong evidence in favor of the sedimentary origin of the salt.

Origin of the motive forces.—The motive force causing the deformation is, however, a much more disputed question. The two most probable theories proposed are:

1) That the upthrust of the salt is an isostatic phenomenon due to the (postulated) fact that the salt core is lighter than the stratigraphically overlying sediments. The specific gravity of rock salt is about 2.15. The specific gravity of the uncultivated soils of the Gulf Coast varies from 1.4 to 1.8. The specific gravity of the subsurface sediments is not available, but on the basis of the following argument should not be distinctly greater than that of the salt. The argument is that if the specific gravity of the component minerals is taken, the specific gravity of the sediments averages about 2.6; if an empty pore space of 30 per cent is assumed, the specific gravity is reduced to 1.7; but as the pore space in most cases will be filled with water, the specific gravity should be around 2.0. In the upper part of the section, where the pore space may be greater, the specific gravity should be lower. With increase of depth, there should be increasing compression and density of the sediments. In the case of a salt dome extending down to great depth or in well-compacted sediments, the salt core may be slightly lighter than an equal column of the adja-

cent sediments, but it is a serious question whether the resultant unbalanced force would be sufficient to overcome both the internal friction of the salt and the great friction between the edge of the salt and the adjacent sediments, especially as the surface of contact is large in relation to the mass of salt involved. In such a dome as Sulphur, the anhydrite-gypsum-limestone cap must have a mass density of around 2.7, and should serve to compensate the slight possible deficiency of density of several thousand feet of salt.

2) That the upthrust has been due to lateral thrust. As the salt domes of Old Roumania are involved in the Carpathian thrusts, it is easy to call upon orogenic thrust to account for those salt domes. The German salt domes are at least molded by the old Saxon folding. The anticlinal folds in which the salt domes of the Magdeburg–Halberstadt Basin occur have the form which the sediments of a collapsed or compressed basin would assume. Such a dome as the Benthe salt dome definitely shows the effects of both Hercynian and Rhenish folding. In the case of the American domes, it is much more difficult to call upon thrust. The characteristic circular outline of the domes suggest the absence of compressive thrust from any direction. The region, furthermore, in which they occur has been one of geologic tranquility since Cretaceous times at least, and shows no signs of compressive folding. There were movements which gave rise to the Balcones–Powell–Luling fault system. But the faults seem to be normal faults. In short, there appears to be no good evidence of lateral thrusts in the Gulf Coast area of intensity sufficient to cause the upthrust of our salt domes.

ORIGIN OF THE CAP ROCK

General statement.—The more probable alternative hypotheses for the origin of the cap rock of the American salt domes are: (1) that it is residual material left behind in the solution of the top of the salt core; (2) that it is a secondary deposit resulting from reactions between vadose water coming in contact with the highly saline waters around the salt core; (3) that it is sedimentary anhydrite and limestone which has been caught up and pushed ahead of the rising salt core; (4) that it is sedimentary limestone which has been caught up and pushed ahead of the rising salt column and which has been altered to anhydrite by sulphate waters.

1) *The residual material hypothesis.* The argument for the residual theory rests largely upon analogy with the German salt domes and the theoretic probability that some solution of the salt and collection of the inclosed anhydrite must take place around the upper part of the salt core. This theory is very generally accepted by the German geologists in explanation of the cap rock of the German salt domes and seems to be plausible for them. The salt of those domes contains a notable amount of anhydrite, 5 to 6 per cent in the case of the "older rock salt," in addition to the intercalated beds of anhydrite. Upturned, intercalated beds of anhydrite in some cases, as at Luneburg, can be seen grading into the gypsum cap. The common, very discordant relation of the salt table and the cap to the structure of the salt core in the German domes, as shown, for example, in Figures 6*b* and 6*c*, shows that a large amount of salt has been removed by solution or erosion from the top of the salt core. The cap of the German domes in a general way resembles that of the American domes, but differs from it in that the cap of the German domes grades into a mantle which extends well down the flank of the salt core; that the cap is not composed in part of limestone, that in contrast to the even, uniform, coarsely crystallized selenite, and the massive, even, uniform, saccharoidal anhydrite of the American domes, the gypsum and anhydrite of the German domes have a confused, uneven, and irregular texture.

The arguments against the residual theory are: (*a*) that salt of the American domes does not contain as much included anhydrite as the German salt, and practically no intercalated beds of anhydrite; (*b*) that the formation of cap rock of the American type, i.e., up to 1,000 feet (300 m.) of homogeneous, even-grained, practically massive anhydrite, by the collection of resdual material is theoretically improbable; (*c*) that the form of the cap-rock mass in most cases is incompatible with formation by the collection of residual material.

a) The argument based upon the apparent lack of sufficient anhydrite in the salt mass is open to considerable question. The character of the salt of the American domes is known best from the salt mines at Weeks, Avery, and Jefferson Islands. But as the absence of cap rock on those domes may reflect the low content of the anhydrite of the salt in those mines, the argument based upon the low anhydrite content there may not be valid for the domes with cap

rock. The knowledge of the salt elsewhere on the American domes is very fragmentary and based on scattered, small cores. Few wells are drilled into the salt; most of these are drilled in only far enough to determine that salt has actually been encountered; and in most cases, only one or two cores of the salt are taken. There is, therefore, very little actually known about the salt masses of the domes other than those which contain the salt mines. At the contact of the salt and cap, "salt and gyp" are in many cases reported by drillers. At Brenham, the "salt and gyp" are known to be interbedded salt and anhydrite. The "salt and gyp," however, seem to be confined to the zone just below the top of the salt.

b) The argument for the theoretical improbability of the formation of the cap through the collection of residual anhydrite is as follows:

The great thickness of some of the caps connotes the solution of improbably thick masses of salt. The cap at Sulphur, Louisiana, is 1,000 feet (300 m.) thick. Even if a high estimate of 10 per cent is given for the average calcium-sulphate content of the salt, the formation of the cap at Sulphur would have involved the solution of 10,000 feet (3,050 m.) of rock salt.

It is, of course, probable that if the salt core is exposed to vadose waters, solution and collection of the residual material will take place. But, though the cap as a whole is in many cases cavernous, the anhydrite is in most cases, where the process of alteration to gypsum has not started, a dense, compact rock which should be very slightly pervious and which, once formed, should greatly impede further solution of the salt. If solution did continue, it should take place along solution channels and fissures rather than uniformly over the whole surface of the salt core, and should give rise to slumping and consequent partial brecciation of the cap already formed. The rock finally resulting from such a process expectably would have an irregular texture and structure, if not showing traces of coarse brecciation. But one of the most marked features of the unaltered anhydrite throughout the Gulf Coast and in the domes of northern Louisiana is its even, homogeneous character. Megascopic brecciation is not uncommon in the rock of the cap, but does not involve unaltered anhydrite.

c) The form of the cap in most cases indicates an upthrust origin rather than a residual origin in the present position of the salt. If appreciable solution takes place, it should take place in the upper flanks as well as on the top of the salt, and a resultant residual cap, therefore, should form a thimble-like mantle extending well down the sides. Forms of the cap in the American domes are shown in Figure 7. The cap, in a few cases, does extend down the flanks, but in

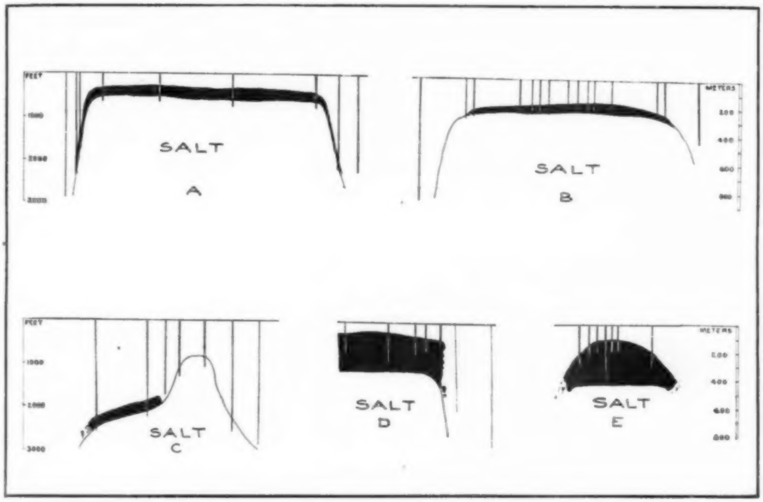

FIG. 7.—Types of cap in the American salt domes

Sections all natural scale. *A*, Palangana; *B*, Bryan Heights; *C*, New Iberia; *D*, East side of Hockley; *E*, Sulphur.

the majority it is a disklike mass resting on top of the salt, and extending not quite to the edge of the salt.

That solution does take place is shown by the central depressions at Anse la Butte, Jefferson Island, and Blue Ridge, but at these domes, the salt comes to within 200 feet (60 m.) of the surface. That the amount of solution on deeper domes is negligible over a very considerable period of geologic time, however, is indicated by the lack of depressions at Big Creek, Stratton Ridge, Pierce Junction, Mark-

ham, and North Dayton. These domes are in a late Pleistocene plain. The absence of a distinct mound in each of these cases indicates the absence of distinct upthrust since the late Pleistocene. The absence of a central depression indicates either that solution was just counterbalanced by upthrust, or that the amount of solution since late Pleistocene is negligible.

2) *The secondary-deposit hypothesis.*—The argument for a secondary origin of the anhydrite and gypsum by the precipitation from solution is that calcium sulphate has a maximum solubility of 7.5 grams per liter in solutions of a salinity of 129.5 grams per liter, that the salinity of sulphate-bearing vadose waters is enormously increased at the edge of the salt through solution of salt, and that with increase of salinity above 129.5 grams per liter, the $CaSO_4$ is precipitated as anhydrite at the edge of the salt. Somewhat similar figures have been quoted to show that the gypsum would be precipitated as the concentration of NaCl decreased.

The arguments against such an origin of the anhydrite and gypsum of the cap are:

a) That the normal Gulf Coast waters are poor in sulphates. G. S. Rogers called attention to the fact that in a series of analyses of waters from depths above 1,500 feet (500 m.), he found the average $CaSO_4$ content to be far less than 1 gram, per liter, and the maximum $CaSO_4$ content of any sample to be 2 grams per liter. The writer's experience has been that the deeper waters are similarly poor in $CaSO_4$, or other sulphates.

b) That the precipitation should take place either on the top and upper part of the sides of the core and form a thimble-like mantle, or at the contact of the salt core with a pervious water-bearing stratum, but that in the majority of cases, the flank of the salt core is bare of cap rock, and in a very large number of cases, part or even the whole of the top of the salt core is bare of cap, and that no indication is recognizable of any connection between the cap rock and pervious or impervious beds.

c) That it is difficult to imagine the secondary deposition of the thick masses of anhydrite without inclusion of the sediments in intimate contact with salt. The postulated sulphate-bearing waters must approach the salt along pervious beds, chiefly sands, or along

problematic fissures. If precipitation should take place back at least a few feet from the salt in the pervious beds, or the fissures, traces of the original beds should be contained in the anhydrite. But one of the striking characteristics of all the cores of the anhydrite and gypsum that the writer has seen is their uniform purity.

A somewhat similar argument can be made for a similar secondary origin of the limestone of the cap, and there is the additional argument that the calcareous sandstones so characteristic of the Gulf Coast salt domes indicate the secondary deposition of lime in the Oligocene, Miocene, and Pliocene sands around the domes. The "sandrock" and the "rock" logged by drillers from around the domes is in a large number of cases sandstone with a calcareous cement, and at Big Creek conglomerate with a calcareous cement. At West Columbia, the amount of "sandrock" is much greater within 1,000 feet (300 m.) of the salt than it is beyond 2,500 feet (750 m.) out from the edge of the salt.

3) *The uplifted sedimentary beds hypothesis.* The argument for the theory of formation of the cap by upthrust of sedimentary beds is as follows:

a) The form of the cap at many domes indicates that it has been upthrust into its present position. At Bryan Heights, Damon Mound, Hockley, West Columbia, and Spindletop, the cap is a disk-like mass of rock that lies directly on the flat salt table, that is several hundred feet (over 100 m.) thick (except at West Columbia), and that stops slightly inside from the edge of the salt. The abruptness of the lateral edge of these thick caps is very striking. A well drilled only some 200 feet (60 m.) in from the edge of the salt table will encounter the full thickness of the cap; and a well 200 or 300 feet away, on the edge of the salt table or on the flank of the salt core, will go directly into the salt without encountering the cap. At Vinton, the cap is similar except that it (and the top of the salt) overhang slightly. If the salt core is thought of as a punch being forced up through sediments, that form of the cap is the one which we should expect to be taken by a core of rock carried ahead of such a punch. Sands and clays should yield by stretching and flowage under the pressure of the head of the salt column. Limestone, anhydrite, or other relatively rigid beds should shear above the edge of the salt, and a disk

of the limestone or anhydrite should ride on the top of the advancing column of salt.

b) Sedimentary anhydrite is possible in beds as thick or thicker than the anhydrite of the cap. The "main" anhydrite of the German Zechstein salt deposits is 125 feet (40 m.) thick, and the Lower Zechstein anhydrite at the base of the deposits is 250–350 feet (70–100 m.) thick. In the Toyah district of Texas, a diamond drill penetrated a flat-lying Permian gypsum-anhydrite series 1,900 feet (575 m.) thick. The lower 1,200 feet (360 m.) is anhydrite and the upper 700 feet (215 m.) is gypsum. The anhydrite is distinctly and regularly banded with black bands (*Jahresringe?*) about 0.2 inch (4 mm.) apart. It is fine grained and in a rough way resembles the anhydrite of cap rock in the Gulf Coast salt domes.

c) The anhydrite and the salt in many cases seem to be intergrown at the contact of the salt and cap. The data in regard to the situation at the contact in most of the domes are vague. According to the drillers' logs, "sand," "crystallized sand," "gumbo and gyp," and "gumbo" intervene in many domes between the cap and the salt. As previously noted, anhydrite is seldom logged correctly by drillers, and appears in the logs as "sand," "crystallized sand," "gyp," or "lime." When cores and cuttings are obtained from the same depth, the core may show solid anhydrite and cuttings may show "gumbo (or shale) and gyp." It is, therefore, certain that much of the "sand" and "gumbo" logged from within the cap is anhydrite. A study of characteristic logs through the cap on the various domes warrants the tentative conclusion that the anhydrite as a rule lies directly on the salt. It is very common for the upper part of the salt to be logged "salt and gyp." That may mean that the anhydrite is permeated with brine, that the anhydrite is permeated with secondary salt, that anhydrite cuttings become mixed with the salt cuttings, or that the salt and anhydrite are interbedded. At Brenham, the salt and anhydrite are known from cores to be interbedded and to grade from one into the other. In a well at Brenham drilled by Mr. Fitzsimmons, the upper hundred feet of the salt, from 2,100 to 2,200 feet was composed of interbedded salt and anhydrite. A core from 2,170 feet (658 m.), shown in Figure 8, was composed of alternating bands of anhydrite and salt. The salt is in clear, transparent crys-

tals, 0.5 to 0.8 centimeters in diameter. The anhydrite is the characteristic saccharoidal anhydrite of the cap of the Gulf Coast salt domes. Although the bands are very definite, there is a very uniform gradation at the contact from the salt into the anhydrite. The relative proportions of the salt and anhydrite were estimated to be 55 to 60 per cent salt and 45 to 40 per cent anhydrite. A similar core taken at a depth of 2,110 feet (639 m.) was reported to have consisted of about 40 per cent salt and 60 per cent anhydrite.

d) The limestone which mantles the cap may have been derived from Oligocene limestone, from Upper Cretaceous limestone, or from

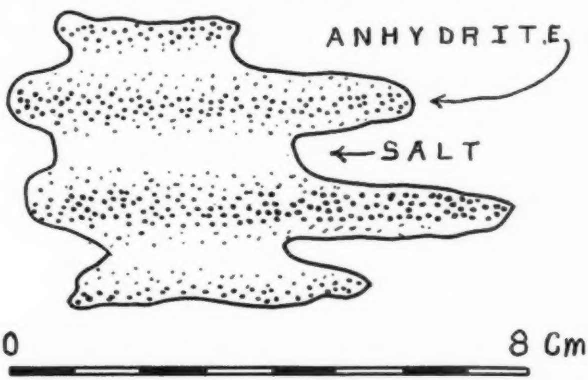

FIG. 8.—Sketch of core of interbedded anhydrite and salt from the Brenham dome

limestones belonging in the same series as the anhydrite. The presence of thick sedimentary Oligocene limestone on the flanks of Damon Mound suggests distinctly the possibility that it may be the source of the limestone of the cap there. Oligocene limestone is known at other domes, but is reported not to be present everywhere. Although it carries a characteristic fauna, traces of the fossils have not been recognized as yet in the limestone of the cap. The salt may come from formations older than Upper Cretaceous, where there are various limestones which could be carried up by the rising salt mass.

e) The argument against the derivation of the cap through upthrust of sedimentary anhydrite and limestone from lower stratigraphic depths is that the thimble-like cap at Palangana, Pine

Prairie, North Dayton, and some of the other domes, doubtfully could only be formed in such a way. The German potash-salt deposits show very definitely the reaction of anhydrite under somewhat similar circumstances. The stratigraphic section of those deposits is roughly as shown in Table VII. The "Older" rock salt is more plastic than the overlying members of the series, and in the salt domes and ridges tends to be extruded through them. Unlike the other members of the series, the "Main" anhydrite did not react to the deformation by bending and stretching, but by breaking; commonly it was torn apart wherever the folding was complicated. In the case of domes of the Stassfurt type, the "Main" anhydrite is found only in the synclines and on the flanks of the anticlines, and in the Hanoverian type of dome, only in the troughs of the synclines and crests of the anticlines. On the basis of the reaction of the anhydrite in the German domes, it is difficult to see how an anhydrite bed overlying an uprising salt core could be bent into a thimblelike mass intimately capping the salt and extending 1,000 feet (300 m.) down the flanks, and how it could maintain that form and position through thousands of feet of uplift. Much more expectably, the anhydrite should shear off at the edge of the salt, as the Oligocene limestone at Damon Mound apparently did.

TABLE VII

GENERAL STRATIGRAPHIC SECTION OF THE GERMAN POTASH SALT DEPOSITS

Formation	Thickness
"Younger" salt series composed of rock salt with minor amounts of anhydrite and clay	200 feet (60 m.)
"Main" anhydrite	130 feet (40 m.)
Potash beds	100 feet (30 m.)
"Older" rock salt	820 feet (250 m.)

4) *The limestone-alteration hypothesis.*—The argument for the derivation of the gypsum and anhydrite of the cap from sulphatization of limestone is based on the known fact that under the action of sulphuretted waters, limestone is altered to gypsum.[1] The anhydrite, however, shows no evidence of being an alteration product; the gypsum shows evidence of being an alteration product only from

[1] Grabau, A., *Principles of Salt Deposition* (1st edition, 1920), pp. 256–57.

the anhydrite; and in cores showing the contact between limestone and anhydrite, the limestone fills cracks fingering out into the anhydrite or gypsum, and is apparently the younger.

As a result of a priori analysis of the problem, and as a result of detailed study in which sections were drawn through the cap for those domes where sufficient data were available, where the composition of the cap and its relation to the supersalt sediments, the lateral sediments, and the salt were studied, and where a megascopic examination was made of many cores of cap rock, the writer has been able to come to no satisfactory conclusion in regard to the origin of the cap rock of the American salt domes. Before this study was well under way, he tentatively held the theory of secondary deposition, but now considers that the least plausible, and considers most plausible the theory that anhydrite and gypsum are derived from sedimentary beds associated with the original salt beds, and that the limestone in part is derived from sedimentary beds at higher stratigraphic horizons and in part is secondary.

OIL AND GAS

There are three general types of occurrences of oil on a salt dome: in the relatively flat-lying shallow sand lenses above the cap and salt; in the rock and cavities of the cap rock; and in the lateral, steeply dipping, often deeply buried sand lenses on the flank of the dome. The presence of the oil is indicated at the surface in many cases by gas seeps, oil or gas in shallow wells, paraffin dirt, and less often by oil seeps.

At Palangana, none of the surface indications of oil or gas are present. A few of the wells have had shows of oil, but no production has been established. On top of the dome, the Sinclair Oil and Gas Company's No. 2 well had a small show of oil at 398 feet (121 m.). Recently a shallow test of the Autrey Oil Company blew out dark-brown oil and water from about that depth. The Simms No. 1 had a slight show of oil in the cap rock at a depth of 710–782 feet (216–239 m.). On the east flank, in the thick bodies of sand in the lower part of the National Oil Company's Nos. 3 and 4, numerous cores had slight odors of oil. On the southwest flank, in the Humble Oil and Refining Company's Singer No. 3, a core of cap rock was

obtained dripping with oil. The Humble's two 4,400-foot (1,338 m.) tests, Singer Nos. 2 and 4, found nothing of interest. Some of the recent sulphur tests had small shows of oil in the top of the cap.

The wells on top of the dome are sufficient to condemn the top of the dome, except for a possibility that wells can be completed which will produce a few barrels of oil per day. The deep dry holes on the south and southwest do not condemn the lateral sands completely, but the chances of future success are poor.

At Piedras Pintas, oil has been produced on top of the dome from shallow depths for a great many years. The field is said to have been discovered through the presence of oil in water wells. At present (January, 1924) there are two small fields about a mile apart. In the eastern field, there are nine wells with a total daily production of 25–50 barrels (3–7 tons) a day. The gravity of the oil is variously reported from 16° to 21° Baumé (sp. gr. 0 96 to 0.93). The oil is said to be about 80 per cent lubricant stock, and about 7 per cent distillate. There are two productive sands, one at 160–180 feet (49–55 m.) below the surface, and the other at 230–324 feet (70–98 m.) below the surface. Structure contours on the lower sand show a moderate dip eastward. The present small productive area has been defined by dry holes on the north, west, and south. The western of the two fields is the older. The field itself and the surrounding territory have been peppered with shallow holes. Most of them had fair shows of oil, many of which could have been made into 1- to 5-barrels-per-day pumpers. Two years ago there were nine producing wells with a total daily production of 25–30 barrels. Some of the wells are said to have come in with a fair initial production, flowing 250 barrels (35 tons) a day for a month. Many of the wells have a long life of 4–8 barrels per day on the pump. The oil is somewhat lighter in color than that of the eastern field, is said to be of 26° Baumé gravity (sp. gr. 0.90), and to have a kerosene content of 40 per cent.

On the flanks there have been several tests, which have had shows of oil but which have failed to establish production. On the west flank, the Empire Gas and Fuel Company's Becker well had shows of 32° Baumé (sp. gr. 0.86) oil and 42° Baumé (sp. gr. 0.81) oil between 3,400 and 3,500 feet (1,034 and 1,064 m.). On the southeast flank, the Peters well had oil shows at 1,300, 1,500, and 2,150

feet (395, 456, and 656 m.). On the east, the Walker well had a good show of oil at 1,291 and 1,337 feet (392 and 406 m.). According to the usual story, each of these wells could have been brought in as a producer if it had been handled properly. The Humble Oil and Refining Company's Walsh No. 1 had a show of oil at 2,896 feet (880 m.) and bailed a little oil at 2,939 feet (893 m.). Their No. 2 had no show worth testing.

FALFURRIAS

INTRODUCTION

The Falfurrias salt dome is one of the very few salt domes of the coastal group in which the cap rock is exposed at the surface, and it is the only one in which the gypsum of the cap rock can be studied directly. The dome has long been known, and was drilled by the Producers' Oil Company in 1911. It goes under various other names, "Las Cuevas," "Gyp Hill," and "Loma Blanca." There has been no drilling since 1911.

Location.—The Falfurrias dome is in the northeastern part of Brooks County, about 7 miles south-southeast of the town of Falfurrias. It is reached by the San Antonio and Arkansas Pass Railroad from San Antonio to Falfurrias, or by the Gulf Coast Lines to Kingsville and automobile to Falfurrias. There is a good hotel at the town of Falfurrias.

Physiography.—The Falfurrias salt dome is on the northern edge of a wind-blown sand area in the coastal prairie. In this general region there is no major relief, but there is a great deal of minor relief due to the presence of innumerable sand dunes, some of them 25 feet high.

At the Falfurrias dome there is Falfurrias Lake, or Laguna Salada, Gyp Hill on the southwest side of the lake, and a hill on the north side. The lake is about 3 miles long by $\frac{3}{4}$ mile wide, and is irregular in shape, with two prongs at the west end and one at the east. The two west prongs mark the enlargement of the mouths of Baluarte Arroyo and Palo Blanco Creek, the east prong, the enlargement of the outflowing creek. Although the western part of the lake half surrounds Gyp Hill, the lake is probably not connected genetically with the salt dome, but is merely a widened stream channel.

Gyp Hill (Fig. 9) is a roughly circular hill with a diameter slightly less than 1 mile and slightly elongated in a north-west-southeast direction. The hill rises 80 feet (24 m.) above the lake and 30–60 feet (9–18 m.) above the general level. The hill on the north side of the lake extends for a considerable distance along the shore of the lake and rises some 20 feet (6 m.) above the general level.

Geology.—Gyp Hill is composed of gypsum, mantled on the lower slopes by wind-blown sands. The gypsum occurs in large crystals 1–8 inches (2–17 cm.) in diameter and 6–18 inches (13–40 cm.) or more in length, the longer axis nearly vertical. Axes of adjacent crystals in most cases are slightly inclined to one another. The crystal form is not expressed, but the various crystals are molded together so that in cross-section they have a roughly hexagonal outline. The crytsals are in layers which are inclined at various low angles and which vary in thickness from a few inches to nearly 2 feet. The prisms of the gypsum are oriented at right angles to the plane of the layer and extend from top to bottom in it. There is a vague tendency for these layers to dip slightly with the hill. In each column there is a tendency for the development of a vertical parting oriented parallel to the tangent to the dome at that point. The gypsum is all in the form of well and coarsely crystallized, fairly clear selenite. Each columnar hexagonal prism is composed of a single crystal. From megascopic examination, the gypsum deposit seems to be very pure.

By far the best exposure of the gypsum is below and south of the crest, in and around an open sink hole which leads into a cave about 10 feet in diameter. The cave slopes downward with the slope of the hill, at an angle of of about 30°, and is large enough to be followed for about 75 feet (25 m.).

Of the subsurface geology little is known. The Producers' Oil Company (the Texas Company) drilled three wells on the southwest slope of Gyp Hill. Two sets of logs are current for the wells. The much more probable set gives the deepest of the wells as drilled 1,000 feet (300 m.) into and abandoned in the "gyp" (gypsum-anhydrite). The less probable set comprises the logs of the three wells drilled respectively to 630, 2,668, and 3,084 feet (192, 811, 938 m.). Some 400 feet (120 m.) of gypsum was logged at the surface, but below

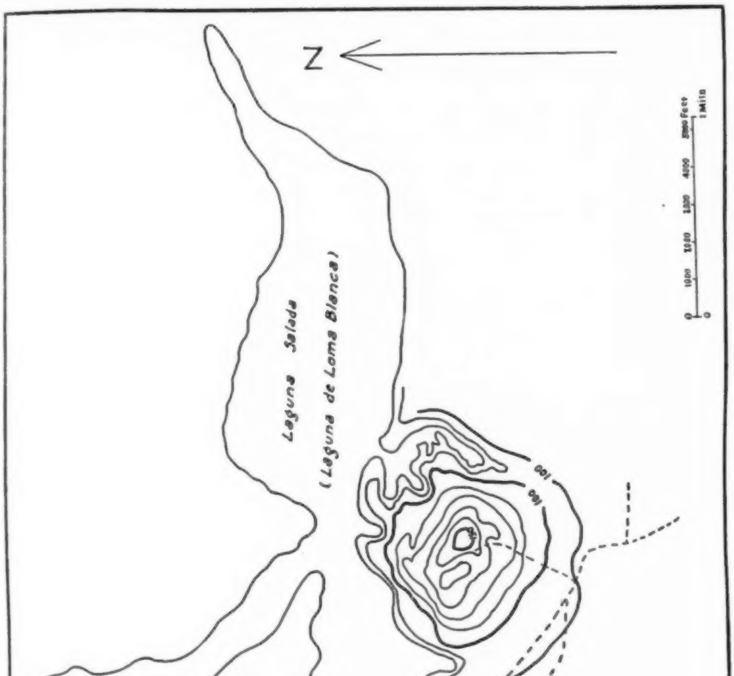

FIG. 9.—Topographic map of the Falfurrias dome

400 feet, little rock was encountered down to 2,830 feet (860 m.) From 2,830 feet to the bottom of the hole, No. 1 had much rock. The amount and distribution of the rock in the section in those wells would be possible for wells drilled through the edge of a slightly overhanging cap rock, such as the one at Vinton. From their position on Gyp Hill, the wells, however, would not be expected to be on the edge of the cap and would not be expected to have the type of section logged in the wells of the second set.

The Falfurrias dome has not been proved definitely to be a salt dome, but on account of the purity of the gypsum mass, the size and shape of the hill, and its position above the general level, Gyp Hill seems to be a salt-dome cap. The size and outline of the probable dome are indeterminate. The chances are that the dome, if present, coincides roughly with Gyp Hill or extends somewhat beyond the limits of this hill. The lake and the hill on the north side of the lake have been interpreted as forming part of the dome. That conclusion does not seem warranted, for the lake appears to be merely a wind-scooped enlargement of the channel of the intermittent stream which flows past the dome. The hill on the north side is probably a dune representing the excavated material.

OIL AND GAS

Surface indications of oil or gas have not been reported at Falfurrias. The only wells which have been drilled near the dome were the Producers' Oil Company Lassater Nos. 1, 2, and 3, all of which were dry. An accumulation of oil in commercial quantity is a possibility at Falfurrias, but the absence in south Texas of known accumulations of oil in commercial quantity in the horizons which could be reached at Falfurrias makes the chance here seem poor. The productive horizons in the Mirando district might conceivably yield oil at Falfurrias. Since, however, the Plio-Miocene section shows a thickening of 2,500–4,000 feet (750–1,200 m.) between the Mirando district and Palangana, since the top of the highest productive horizon in the Mirando district is barely reached at Palangana, and since Falfurrias is about twice as far back from the outcrop of the Plio-Miocene as Palangana those productive horizons are probably deeply buried at Falfurrias. On account of the accumulation

of gas at Kingsville, Whites Point, and elsewhere in south Texas, there is a better chance for gas at Falfurrias than for oil.

SAL DEL REY AND SAL VIEJA

INTRODUCTION

Sal del Rey and Sal Vieja are somewhat similar saline lakes west of Raymondville, in Willacy County. Although there is a small export trade in salt from Sal del Rey, and although these lakes have long been points of interest to the Gulf Coast geologists and others, they seem not to have received attention in the literature. They present some evidences of being salt domes and are usually classed as possible salt domes. They have never been proved to be salt domes, and may be merely wind-scooped depressions.

Location.—Sal del Rey is 17 miles (27 km.) west-northwest of the town of Raymondville. It is reached by the Gulf Coast Lines to Raymondville and then by automobile 11 miles (18 km.) due west over the La Coma (MaAllen and Falfurrias) road, and 7 miles (11 km.) northwest over country trails. Sal Vieja is about 7 miles (11 km.) west and 3 miles (5 km.) north of Raymondville. It is reached by automobile from Raymondville over roads and ranch trials.

Physiography.—The region in which Sal del Ray and Sal Vieja lie is the southern equivalent of the flat, featureless, grassy coastal prairie of southeast Texas and southwestern Louisiana. This plain has been much affected by wind activity, and is now a rolling plain of sand dunes, of wind-scooped basins, and of irregular wind-drifted masses of sand, silt, and clay. The region is covered with a dense growth of mesquite.

Sal del Rey is a roughly elliptical lake over 1 mile in length by $\frac{3}{4}$ mile in width (1.5 by 1 km.). It lies in a shallow basin which has no outlet, and no streams flowing into it. It is bounded on the east and north by a nearly flat rolling plain, on the south and southwest by a low ridge rising 10 feet above the plain to the east, and about 20 feet above the general level to the south, on the north-northwest by a faint ridge, and on the west by a shallow depression about one-fourth the size of the main basin. Immediately northwest of the depression is a hill which is the highest point in this vicinity. As this hill lies immediately to the lee of the depression from the prevailing

winds and is of approximately of the same size as the depression, the hill and depression are probably due to wind activity.

The size and shape of the basin and the presence of the roughly concentric ridge on the south and southwest are suggestive of a salt-dome mound with central depression. It is more similar to the erosional basin and ring of hills of Palangana than to the deformational mounds and central depressions of the salt domes of the coastal-prairie belt. But Sal del Rey lies in a belt which has not suffered erosion except in the form of superficial wind sculpturing, and therefore should have a deformational mound, if any. Wind-scooped basins are common in this general region, but in no case known to the writer are they as large as Sal del Rey. In some cases the basins are occupied by fresh to brackish, most commonly wet-weather lakes.

Sal Vieja (Fig. 10) consists of two saline lakes lying in a shallow elliptical depression which is $3\frac{3}{4}$ miles long by 2 miles wide, (6 by 3 km.) the major axis trending east-northeast to west-southwest. The western and larger of the two lakes lies in an elliptical basin about 2 miles long by $1\frac{1}{2}$ miles wide (3 by 2.5 km.). It is completely enclosed and has no outlet. At the west end of the basin a fair-sized valley comes in from the west. In the lake, there are four islands rising to within 5 feet of the general level of the surrounding country. The shores of the lake and of the islands show the effects of considerable lateral wave erosion. The bottom of the lake extends very slightly below sea-level. The eastern of the two lakes, sometimes known as Yturria saline, lies in a circular basin with a diameter of about 1 mile (1.5 km.) and with a size about one-half that of the western basin. It is somewhat shallower than the main basin and shows somewhat less lateral wave erosion on the shores. Its bottom lies at about sea-level. Unlike the main basin, it dries up completely in times of drought. The basin is completely enclosed, without outlet or entering streams. The two basins are separated from each other by a flat-topped ridge about 1,500 feet (450 m.) across, which rises about to the general level of the surrounding country.

Sal Vieja is bounded on the northeast, east, and south by the flatly rolling plain of the region, with broad, low, rolling hills rising to a general elevation of about 50 feet above sea-level, and with

broad, shallow valleys; on the southwest by a few low hills; and in the northwest quadrant by a distinct range of hills which is ½ mile (1 km.) wide and is concentric with the edge of the lake. The crests of the hills rise about 50 feet (15 m.) above the general level, 70 feet (21 m.) above the lake level, and 85 feet (25 m.) above sea-level.

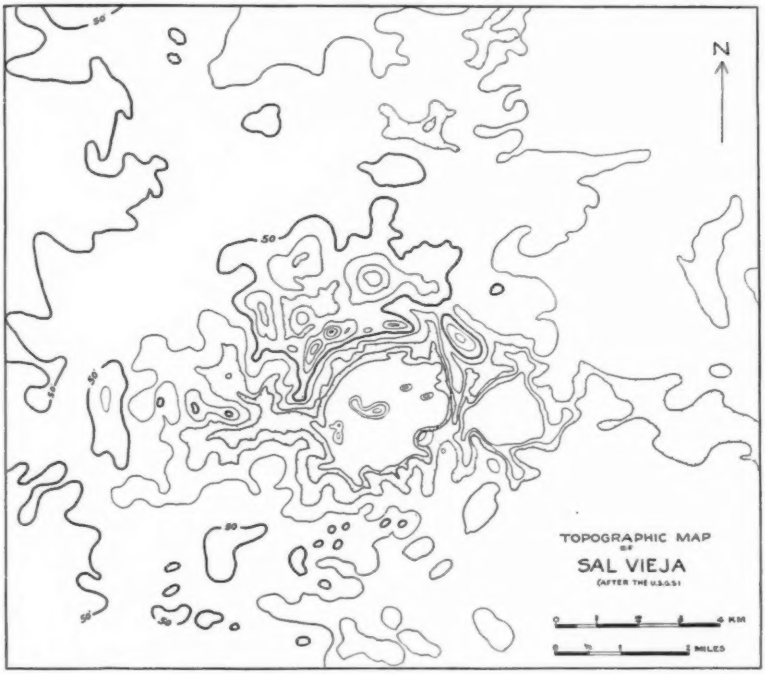

FIG. 10.—Topographic map of Sal Vieja

The form, shape, and size of the Sal Vieja basin and the form and position relative to the basin of the range of hills are suggestive of salt-dome topography, but, as in the case of Sal del Rey, the topography is not quite the deformational type of expression which should characterize a salt dome here. The position of the range of hills on the lee side of the main lake from the prevailing winds, the presence of the islands, and the congruence of the crests of the islands

and of the ridge between the two lakes with the general level are suggestive of wind activity as the cause of the basins.

GEOLOGY

The beds which are exposed in the shore-line bluffs of Sal del Rey and Sal Vieja and which normally form the surface of the surrounding region are light-colored clays and sandy clay with some beds of fine sand, which are to be referred either to the Reynosa or the Recent fluviatile deposits. The clay at the surface washes out readily and leaves a sandy soil. Most of the surface is covered by wind-drifted material.

The waters of Sal del Rey, of the main lake at Sal Vieja, and of Yturria Saline are all brines, that at Sal del Rey being notably concentrated. Except after heavy rains, the brine is fully saturated

TABLE VIII

SECTION THROUGH SALT AT SAL DEL REY

	Thickness
Rock salt	2 inches (5 cm.)
Black clay containing salt crystals	4 inches (10 cm.)
Clear rock salt	3 inches (7.5 cm.)
Black clay	2+ inches (5+ 4 cm.)

and depositing rock salt. The latter covers the floors of the lake and extends up the beach. According to the accounts of local Mexicans, there is 16 feet (5 m.) of solid salt in the center of the lake. At a point about 25 yards from the center, however, the section shown in Table VIII was found. At times of drought, Sal del Rey dries up completely. The water of Sal Vieja is not so saline as that of Sal del Rey, and the water of the main lake at Sal Vieja is slightly more saline that that of Yturria Saline. In normal seasons, there is a thin salt crust on the beach, but there is no rock salt in the lake; but in times of drought, Yturria Saline dries up completely and a ½-inch layer of rock salt is deposited over the lake bottoms of both Yturria Saline and the main lake. The latter never dries up completely.

Nothing is known of the subsurface geology at either Sal del Rey or Sal Vieja. The nearest well to the former is an 820-foot (250 m.) artesian well three miles (5 km.) east of the lake. At the latter,

there is a 1,000-foot (300-m.) water well about 1,000 feet (300 m.) back from the edge of the basin on the Richards ranch. It has a cool, very slightly saline water. One-half mile west of the lake, on the Corbett ranch, is an 800-foot (240-m.) well which has a slightly warm and slightly more saline water. Neither well flows.

A minor feature at Sal del Rey and Sal Vieja is the vesicular texture which the sands of the shores have shown at the times of the writer's visits. The sand had a texture much like that of a very vesicular lava or that of a very thoroughly risen bread. The individual vesicules were rounded and about 0.08–0.12 inches (1.7–2.6 mm.) long by 0.05–0.08 inches (1.1–1.7 mm.) in diameter. Although as a whole the orientation of the longer axes was heterogeneous, there was a tendency to parallelism to the surface. The sand was composed of somewhat irregular, medium-to small-sized grains, in a few cases with a small amount of clayey material. The vesicular sand was found nearly everywhere around Sal del Rey and Sal Vieja between the existing wave-splash line and the foot of the bluffs. It formed a zone 1–2 inches thick about 1 inch below the surface. At the surface there was a crusty layer of sand, in most cases overlain by a film of salt. At Sal Vieja the section shown in Table IX was noted. The area of vesicular sand had been under water three weeks before the time of the writer's first visit. The weather had been extremely hot; maximum temperatures of 112° F. (44° C.) had been registered at a U. S. Weather Bureau Co-operative Observer Station in Raymondville, and the waters of the lakes had evaporated rapidly. The explanation of the vesicular sand may be found in a rapid vaporization of the moisture in the beach sands with consequent simultaneous formation of bubbles and precipitation of the salt in the interstices between the bubbles. The sand grains would be kept at the surface of the bubbles or between them by surface tension and would be cemented together by the precipitated salt to form the walls of the vesicles. As it is dependent on the salt cement, the structure should be rather ephemeral and should crumble before unsaturated brine solutions. But as in one place it survived successive burial by clay, sand, and clay, under favorable conditions the structure might be preserved and be found in the rocks.

Exploitation.—Surface indications of oil and gas are not present at either Sal del Rey or Sal Vieja. No shows of oil or gas are reported from the two water wells drilled near Sal Vieja, and there has been no exploitation for oil at either place.

The salt at Sal del Rey has been worked to a small extent for a great many years by Mexicans. The upper salt crust, which is some 2 to 4 inches thick in the center of the lake, is broken into blocks and is loaded into small wagon trains which come out of Mexico and take it back into the interior. The amount of salt exported is small.

ORIGIN OF SAL DEL REY AND SAL VIEJA

The two most probable possibilities for the origin of the two salines are (1) that they are the surficial expressions of salt domes, or

TABLE IX

SECTION AT THE BEACH, SAL VIEJA

	Thickness (Inches)	Depth (Inches)
Clay	0.3	0–0.3
Vesicular sand	0.5	0.3–0.8
Clay	0.3	0.8–1.1
Vesicular sand	0.5	1.1–1.6

(2) that they are wind-scooped basins in which there has been concentration of surface water.

1) The evidence possibly in favor of the first method of origin is: (*a*) the lake basins of the form and size of salt domes, and of considerable resemblance to the central depressions of salt domes; (*b*) the partial, concentric rim of hills on the edge of the basins, roughly similar to the ring of hills around Palangana; (*c*) the concetrated brine and, in the case of Sal del Rey, the salt beds; (*d*) the position of the two salines, which is very closely on the line through Palangana, Piedras Pintas, and Falfurrias. It is strange that with only one line of salt domes known in the whole of south Texas, the only two large salines should lie on this line.

2) The evidence in favor of the second possibility is as follows:

a) Although apparently fulfilling the formula for a salt-dome

mound and central depression, the topography is not exactly that of the deformational type of salt-dome mound with a central depression, but is more similar to the erosional type characterized by Palestine and Palangana. But from the position in the coastal prairie, any surficial expression, if present, must be of the deformational type.

b) From the approximate congruence of their crests with the general surface, the islands in the main lake at Sal Vieja and the flat-topped ridge between the main lake and Yturria Saline suggest that they are erosion remnants of the general surface.

c) Formation of the topography through wind activity is distinctly plausible. The area is one of semiaridity; wind action is strong, and sand dunes and wind-scooped basins are common. The prevailing wind is from the southeast, and the distinct rim of hills in each case is in the northwest quadrant.

d) The brine and the salt deposits do not necessarily indicate association with a salt dome. The water of many of the wind-scooped basins of the region is reported to be brackish or briny. Water so salty that the cattle will not drink it is found in abundance at depths of 20 to 50 feet (6 to 15 m.) in the general region around Sal del Rey and Sal Vieja. In view of the very hot, dry weather that prevails, concentration of this salty ground water into brine should take place in any closed basin whose bottom lies below the ground-water level. The formation of the brine at Sal del Rey and Sal Vieja by the concentration of normal surface waters is, however, not an evidence against the salt-dome origin of the topography. If a salt-dome central depression extended below the ground-water level, the concentration would take place similarly to a wind-scooped basin.

e) The presence of potable water at 1,000 feet (300 m.) in the Richards ranch water well on the south edge of Sal Vieja is not preclusive, but is distinctly unfavorable to the hypothesis of the existence of a salt dome beneath Sal Vieja. Waters at that depth from close to a salt dome most commonly are distinctly salty.

A definite conclusion whether or not Sal del Rey and Sal Vieja represent the surface expression of salt domes is not warranted by the evidence available.

OIL AND GAS POSSIBILITIES

If Sal del Rey and Sal Vieja are salt domes, structure favorable for the accumulation of oil is presumably present. On account of the lack of oil or gas seeps around them, and on account of the lack of known commercial accumulation of oil in the coastal section of south Texas, the chance of the existence of commercial pools on or around them is poor. In view of the accumulation of gas at Kingsville, Whites Point, and Three Rivers, there is a better chance for the discovery of gas, but with the absence of gas seeps, even this chance does not seem good.

If Sal del Rey and Sal Vieja are not salt domes, the chance of the existence of oil or gas pools underlying them is only that of acreage chosen at random in this area.

SMITH CORKILL

The Smith Corkill possible salt dome lies 15–20 miles (24–30 km.) west of Benavides in Duval County. The features suggesting the presence of a salt dome are four hills which roughly outline a circle. The hills are composed of chalcedonic and opalized sandstone and of intercalated masses of kaolinized clay. These silicified sandstones and the kaolinized clay are similar to the silicified sandstones and the kaolinized clay at Piedras Pintas. Somewhat similar silicious knobs are found not far to the west and southwest. Smith Corkill may be, but probably is not, a salt dome. There is considerable evidence, according to Deussen, for the presence of a basaltic knob close to these knobs, and he suggests that they may be due to hydrothermal activity of emanations from that volcanic neck.

LA LOMITA

La Lomita, a hill on the Rio Grande, 6½ miles (10.5 km.) south of Mission, is reported by Trowbridge to be a possible salt dome. It is described as a small hill, some 1,600 feet (500 m.) in diameter, rising conspicuously above its alluvial surroundings, and, according to Trowbridge, exposing abnormal materials and abnormal dips, which, however, may not represent true bedding-planes. Three wells are reported to have been drilled on the hill without encountering shows of oil. At least one of the wells was drilled below 3,000

feet (900 m.). The log of one of the wells was examined by the writer and showed nothing indicative of the presence of a salt dome. La Lomita seems probably not to be a salt dome.

CHAPEÑO

Chapeño is about 35 miles south of Brownsville, in the state of Tamaulipas, Mexico. It is usually classed as a possible salt dome. The evidence for the presence of a salt dome is a low swell in the flat, low coastal prairie, with sulphur, sulphur gas, and sulphur water on the top of the swell. It is described in another paper of the symposium.

KINGSVILLE AND WHITES POINT

The Kingsville (Kleberg County) and White Point gas fields are sometimes spoken of as salt domes. As the respective papers on those fields will show, doming is probably present in each, but no evidence of salt-dome formations (salt or cap rock) have been found in the deep wells which have been drilled on them.

They are probably to be classed with the Goose Creek type of structure, which have not been demonstrated to be salt domes.

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THE BIG HILL SALT DOME, JEFFERSON COUNTY, TEXAS

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ABSTRACT

Although salt has not been penetrated in drilling, the Big Hill salt dome, Jefferson County, Texas, in all probability is a characteristic Gulf Coast salt dome. It has a very distinct salt-dome mound, a characteristic salt-dome cap. One well has been completed as a producer. The oil is typical Gulf Coast crude.

LOCATION

Big Hill is in the southwestern part of Jefferson County, Texas, about 12 miles from the Gulf of Mexico. It is most easily reached by train or automobile from Beaumont. The Gulf, Colorado & Santa Fe Railroad passes through Hamshire, 11 miles northwest of the "Hill." All freight and supplies come to Hamshire by rail and are hauled in by wagon or truck during dry weather. During wet weather the road is almost impassable.

HISTORY

Record of the early history of the development of Big Hill is very unreliable. Little was written about it during the period of early exploration, and all that can be learned from men who were more or less in touch with the development is contradictory.

It appears that the first well was drilled by the J. M. Guffey Company in 1901 on the southeast side of the mound. This well hit cap rock at 370 feet and continued in it to its total depth of 1,600 feet. Oil showings were found at several horizons, but they were not strong enough to produce. Shortly after this well was completed, the Texas Oil Fields Ltd. Company entered the field and drilled three wells. One of these wells was near the J. M. Guffey well, and the other two were north of the mound. Neither of the later

[1] Chief geologist, Houston Oil Company

wells found anything but unconsolidated material to their total depth, which was 2,600 and 3,000 feet, respectively.

The Big Hill Mound seems to have been neglected for a number of years, until about 1913, when an association headed by S. W. Pipkin, a large landowner in this district, drilled a well on the northeast flank to a depth of 1,675 feet. This well was abandoned in a porous rock, but had several showings in sands above the rock. Encouraged by these showings, the Texas Exploration Company and the Texas Company started development at about the same time. The Texas Exploration Company drilled four wells on the top of the dome and its south flank, and the Texas Company drilled two wells off of the south flank. All of the Texas Exploration Company wells struck cap rock and were abandoned at shallow depths; the deepest went to 1,385 feet. The wells of the Texas Company were drilled to 3,505 feet and 2,922 feet, respectively, and neither encountered either cap rock or oil in commercial quantities.

In 1921 the Houston Oil Company, of Texas, took leases covering the south half of the hill. To date, twelve wells have been drilled—ten on the southeast side of the dome and two on the west side. Of the wells drilled on the southeast side, three have been abandoned in porous rock, one completed as a producer, and the others abandoned at various depths down to 4,049 feet. Both the wells drilled on the west side have been abandoned in cap rock. The well which was finished as a producer came in September 1, 1923, making 400 barrels per day of clean oil. Water soon began to come in and the well declined rapidly. At the present time it is producing 30 barrels of 19.5° Baumé gravity oil per day and about 200 barrels of water. This oil is the typical Gulf Coast green oil with high lubricating oil content.

During 1923 a well was drilled on the east side of the dome by the Gulf Production Comapny to a depth of 4,780 feet. At the present time the Houston Oil Company has two rigs running on the west side of the Hill.

GEOLOGY

Big Hill is superimposed on a low ridge which is evidently an old shoreline and can be traced for many miles both east and west

of the mound. This ridge has a uniform elevation of about 10 feet above sea-level, while Big Hill rises to an elevation of 35 feet on the north side and 31 feet on the south with a shallow saddle between the two points of greatest elevation.

Because of the small amount of drilling which has been done, the only cross-section available is across the south side of the hill along the line *A–B* (Fig. 1). This section is made with the top of the cap rock as control.

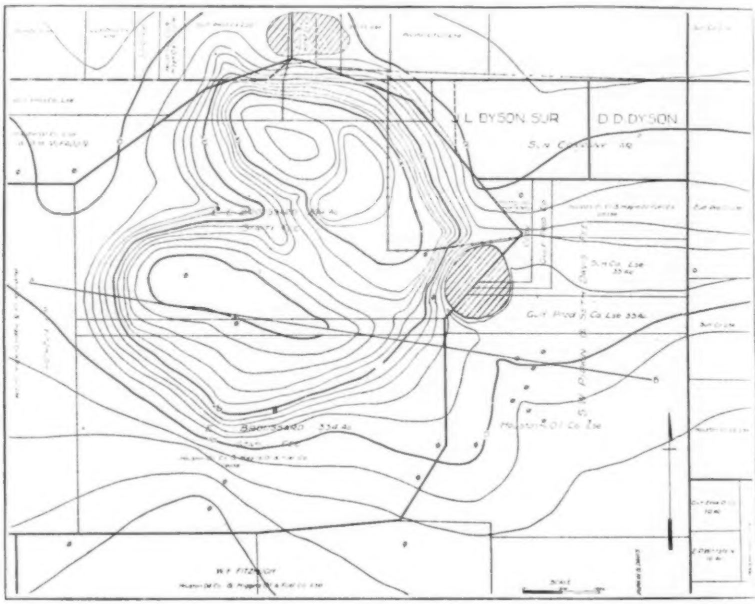

FIG. 1—Map of Big Hill salt dome

Although no salt mass has been found in any of the wells, it is reasonable to suppose that there is such a mass underlying the cap rock. The cap rock here is composed of a porous dolomitic limestone, gypsum, anhydrite, and a very porous limy sandstone which lies on the outer edge of the cap. It is very similar to that above known salt masses. Along the line *A–B* the cap rock has a known width of 6,000 feet, its west edge being still undetermined.

The cap dips at a very high angle on the east side, while on the west it has an apparent dip of about 30° (Fig. 2). From this and the shape of the surface elevation we are of the opinion that the thrust of the salt mass came from the west or southwest and swung to the

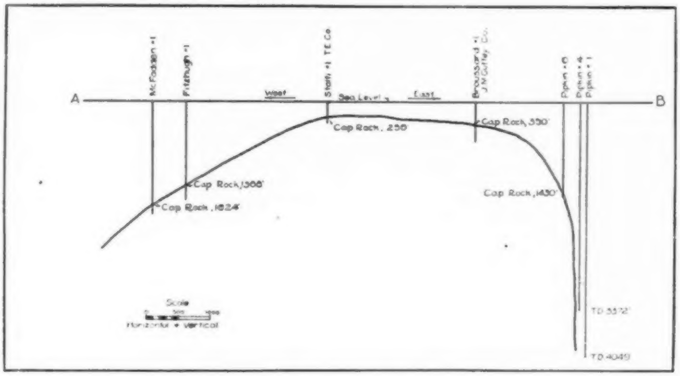

FIG. 2—Cross-section along line A-B of Figure 1

north with a fracture through the saddle between the two points of greatest surface elevation. The lateral beds on the southeast side seem to be very badly fractured, while on the west they are fairly regular. Fossils from a depth of 3,270 feet in Pipkin No. 4 have been classified as Fleming in age.

THE SPINDLETOP SALT DOME AND OIL FIELD JEFFERSON COUNTY, TEXAS[1]

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ABSTRACT

The Spindletop oil field was the first and one of the most brilliant of the Gulf Coast oil fields. Spindletop is a characteristic Gulf Coast salt dome and is composed of a steep-sided, relatively flat-topped, circular salt core with a diameter of about 1 mile, and with a limestone, anhydrite, gypsum cap surmounting the salt. Most of the oil was produced from the porous cavernous limestone at the top of the cap. The early gushers have never been equaled in the United States for the size of their daily flush production. Few fields in the United States of like size, 265 acres, have had as big a production, thirty million barrels in the first three years, and a total of over fifty million barrels to date.

INTRODUCTION

Location.—Spindletop is in the northeast part of Jefferson County, in southeast Texas, about 3 miles south of Beaumont. The field is reached by means of the Sabine and East Texas Railroad, the interurban line running from Beaumont to Port Arthur, but best by automobile via either the upper or lower highways from Beaumont to Port Arthur.

History.—The Spindletop oil field is one of the oldest and most famous fields in the Gulf Coast region. The name was derived from a so-called island of timber, located on the northeast corner of the John A. Veatch survey, near the dome. The contour of the timber resembled an inverted spindletop when viewed from surrounding prairie.

The oil history of Spindletop dates back to about 1890 when one Patillo Higgins insisted confidently on the presence of oil under Spindletop. His convictions were based on two indications: the escape of gas from two points known as the copperas pond and the mud springs; and the distinct topographic elevation of the area above the prairie. Though nothing was known about salt domes or oil fields in the Gulf Coast at the time, Mr. Higgins laid out a section known as Gladys City and in 1892 formed a company known as the Gladys City Oil Company. Later, several water wells were dug to a depth of 15 to 20 feet, and

[1] Printed by permission of the Rycade Oil Corporation.

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sour waters containing various minerals were obtained. In addition to other indications, incrustations of sulphur were found in the soil.

The first oil tests were drilled in 1893. W. B. Sharp and J. S. Cullinan drilled a 418-foot well with a small rotary. Hearing that a gas sand had been passed up at 60 feet in the Sharp-Cullinan well, Mr. Higgins drilled nearby, and at about 60 feet completed a small gasser which supplied enough gas to fire his boiler. Other tests were drilled at about the same time by Looney and the Savage Brothers.

In 1900, Captain Anthony F. Lucas, a mining engineer, came to Beaumont. As the result of his experience with salt domes in southern Louisiana, he became convinced that sulphur, oil, and gas occurred beneath such domelike mounds as at Spindletop. Backed by Guffey and Galey, Lucas drilled his No. 1 well on the apex of the dome and though he lost it at a depth of 575 feet, two demijohns of 17° Baumé oil were obtained. The well that was later known as the "Lucas gusher," the fame of which spread around the world, was started in October, 1900, on the southwest slope a short distance from the apex.

On January 10, 1901, while drilling at a depth of 1,139 feet (352 m.), the well blew in unexpectedly with an enormous production that was conservatively estimated as 75,000 barrels (10,900 metric tons) per day. It is said to have shot a 6-inch stream of oil 200 feet into the air. Although oil had been showing in the ditch, no production had been expected and no preparations had been made to handle it. The well ran wild and flooded the surrounding prairie with oil. After flowing a few days, the well caught fire, and when it was finally brought under control, the casing was found to have collapsed. The well was never reconditioned.

The Lucas gusher was probably the first large or even moderate-sized well that was drilled with rotary tools. In some of the earlier tests, attempts had been made to drill with cable tools, but these had been unsuccessful on account of the loose, unconsolidated character of the sediments. Captain Lucas, therefore, turned to the rotary method which had been used in a rudimentary form at Corsicana, in a few water wells, and in one of the previous tests at Spindletop. He had, however, to do considerable pioneer work in redesigning it and in developing its technique.

Following the completion of the Lucas gusher excitement was high and land formerly worth $10 an acre jumped to thousands of dollars an acre. The Gladys City Oil Company secured the services of Captain Lucas to manage the drilling on its lease. Shortly they changed their name to the Gladys City Oil & Gas & Mfg. Company and began subleasing the 2,200 acres which they had leased for a period of twenty years. The land was assigned to companies and individuals without any cash bonus, allowing free oil and gas for fuel and retaining only one-tenth royalty. The company ceased drilling operations and became a royalty company.

Much land was obtained from the Veatch League, and the entire dome was leased and divided into various sections. The most prominent and important

divisions are the Gladys City, in approximately the center, the McFaddin tract and Keith Ward to the south, Hogg-Swayne to the southeast, Yellow Pine and Lone Acre to the north, and Block No. 21 to the west. The most intensive drilling was on the Hogg-Swayne and Keith Ward tracts, where derrick legs overlapped one another, and from one to four holes were drilled under the same floor. By the summer of 1901, the boom was in full swing. Derricks were so closely spaced that derrickmen, fearing a blow-out, are said to have put out planks to neighboring derricks, in order to permit retreat from one derrick top to another out of the danger zone. The field reached the height of drilling operations and production during the year 1902 when the amount of oil gauged was 17,420,949 barrels (2,541,000 tons). Not included is an unknown very large amount of wasted oil. The wells were brought in so fast that it was utterly impossible to provide storage for all the oil, and, as a result, many thousands of barrels of oil covered the prairie and were lost.

By the end of 1902, the crest of the boom had passed and the drilling began to decline. During 1903, the production dropped to half that of the preceding year, but was still very large, even for Gulf Coast oil fields of the first class. By 1904, the limits of the field were pretty well shown to be confined to the area of the mound; the host of wells which were drilled around the edges of the field failed to bring in extensions to it, and successful new drilling was largely on proved acreage. The production dropped to 40 per cent of that of the preceding year. In 1905 it dropped again by 50 per cent, and for the next eight years it declined slowly but was still of moderate size. By 1915, the annual production had dropped below 400,000 barrels, and operations came to consist of working over old wells and drilling new wells to sands that had been undetected or ignored in the early days. During the past year, eight new wells were drilled, and the daily production averaged about 850 barrels (124 tons).

As the result of the discovery in recent years of production from deep lateral sands about various salt domes, exploration was renewed around the Spindletop dome. The Texas Company drilled a deep test into the salt on the northeast edge of the dome, and Wilson and others drilled nearby. The Spindletop Deep Well Company in the first part of 1917 drilled a test to 3,832 feet (1,150 m.) on Block No. 27 of the LaSalle Townsite Company. Many of these offside wells reported good shows, but none found oil in commercial quantity. Drilling in the latter half of 1918 on the northeast edge of the dome, the Gulf Production Company completed their McFaddin No. 1 as a 250-barrel (36-ton) producer at a depth of 2,947 feet (898 m.). The well in some way became junked and was never reconditioned. The Gulf Production Company's No. 2 McFaddin, 500 feet (150 m.) to the southeast of No. 1, was then drilled to 3,278 feet (999 m.); No. 3 McFaddin, a short distance off the southeast edge of the salt, to 3,780 feet (1,152 m.); No. 4 McFaddin was drilled 1,000 feet off the salt on the northwest into the top of the salt; and Gladys City No. 1 was drilled to 4,700 feet. About the same time, Marrs McLean drilled to 3,700 feet (1,128 m.) a short distance off the salt on the west. None of these wells found anything more than small

shows of oil. In 1922, the Rycade Oil Corporation (formerly Amerada Petroleum Corporation) drilled its McFaddin No. 1 to a depth of 4,162 feet (1,296 m.), about 700 feet (200 m.) east of the Gulf Production Company's McFaddin No. 1. In a sand at 3,895 feet (1,187 m.) the well tested fifteen to twenty barrels ($2\frac{1}{2}$ tons) per day, on the swab. The Rycade Oil Corporation drilled its McFaddin No. 2 to a depth of 5,400 feet (1,647m.) just off the southeast edge of the salt

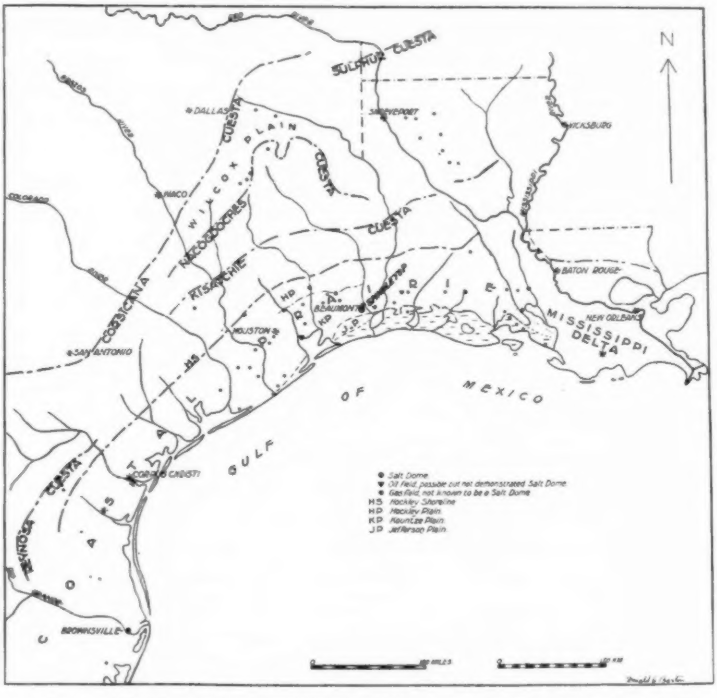

FIG. 1.—Physiographic map of the Texas-Louisiana salt-dome area showing the position of Spindletop.

and in 1924 drilled its Gladys City No. 1 to a depth of 3,962 feet (1,207m.) on the northwest flank of the dome.

PHYSIOGRAPHY

The physiographic province in which the salt domes of Louisiana and Texas occur is the Gulf Coastal plain (Fig. 1). In southeast Texas and northwest Louisiana, it is composed of the Coastal

Prairie, the Kesatchie Cuesta, and other cuestas farther inland. The character of this physiographic province is set forth and its component plains and scarps are described elsewhere by the senior author.[1]

The characteristic surface expression of the domes of the Coastal group which are marked in the topography is a mound of approximately the same diameter as the salt core, in shape very much like an inverted wash basin, with or without a central depression. The height of the mounds ranges from a few feet to 200 feet (60 m.). The salt-dome mound at Spindletop is one of the fainter type without a central depression, and it rises only some 10 to 15 feet above the general level of the Kountze plain, and 30 feet above sea-level. The mound is roughly circular in outline. On the north, east, and west sides, the mound slopes gradually and without break into the surrounding prairie. On the south side, there is a much steeper slope, which, however, seems to be due largely to the erosion of a shallow valley across the southwest edge of the dome. The mound is not as large areally as the salt core, but seems to coincide in position more with the cap rock, which covers only about two-thirds of the top of the salt.

GEOLOGY

Surface.—Spindletop mound is composed of sands which may be Lissie or Beaumont. The surrounding prairie is composed of clays, sandy clays, and clays of the Beaumont formation.

Subsurface.—Spindletop is a characteristic Gulf Coast salt dome, and as such is composed of a stock like core of rock salt, sedimentary beds dipping quaquaversally away from the salt core, and an anhydrite-gypsum-limestone cap on the top of the salt (Fig. 2).

The salt core is roughly circular in plan, and about 1 mile (1.6 km.) in diameter. It is delimited on the northeast by the Texas Company's McFaddin No. 1, which struck the salt at a depth of 2,579 feet (787 m.), the Gulf Production Company's McFaddin No. 2, and the Rycade Oil Corporation's No. 2 McFaddin, which were drilled, respectively, to depths of 3,278 feet (999 m.) and 4,162 feet (1,296 m.) without striking salt; on the southeast by the Gulf Production Company's No. 4 McFaddin which struck the salt at a

[1] Donald C. Barton, "Pine Prairie Salt Dome," this *Bulletin*, Vol. 9, to appear later.

depth of 1,684 feet (513 m.), and No. 3 which went to a depth of 3,780 feet (1,152 m.) without striking salt; and on the west by a well just west of the railroad track which went into the salt at a depth of 2,000 (?) feet (600 m.), and by Marrs McLean No. 1 which went

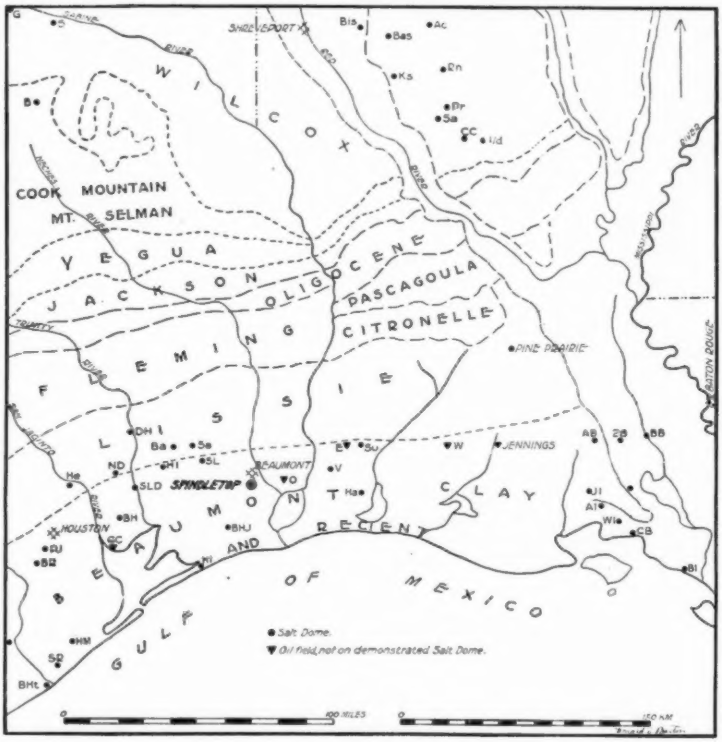

FIG. 2

to a depth of 3,700 feet (1,128 m.) without striking the salt. On the north, the edge of the salt has not been shown clearly by the drilling but on the basis of the symmetry of the surface mound, and of the rest of the edge of the salt, it seems probably to lie just south of the railroad crossing on the Beaumont road from the field.

The salt core has a relatively flat top and steep sides. In the center of the field, the top of the salt is found at depths of 1,200 to

1,600 feet (300 to 500 m.). The Iowa Beaumont well, drilled near the center of the dome, struck salt at 1,200 feet and was abandoned in it at 1,790 feet. In Higgins No. 2, drilled 2,000 feet north of the Iowa Beaumont well, the top of the salt was reported as at 1,647 feet (501 m.). On the east side, the Texas Company's No. 1 well struck salt at 2,579 feet and abandoned the well in it at 2,626 feet.

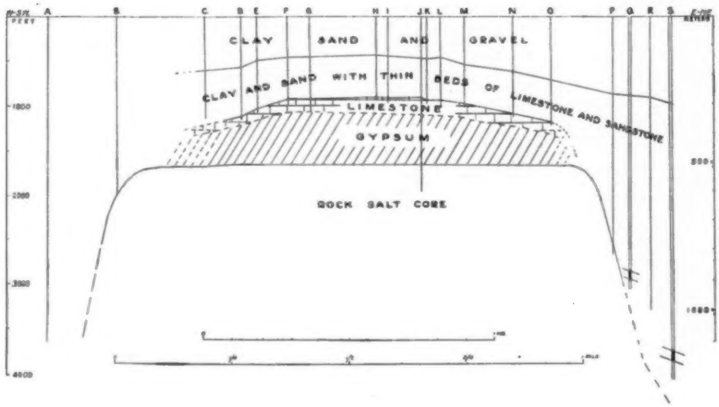

Fig. 3.—West-east section through the Spindletop salt dome (partly after Fenneman)

A = Marrs McLean, Gladys City No. 1
B = ?
C = Lucas No. 2
D = Guffey No. 2
E = Higgins No. 2
F = Beaumont Confederation No. 2
G = Robertson No. 2
H = Keith Ward No. 2
I = Heywood No. 2
J = Higgins No. 2
K = Heywood
L = National No. 1
M = National No. 2
N = Beaumont Pacific
O = Denver Beaumont
P = T. T. Co. No. 1
Q = Gulf Prod. Co., McFadden No. 1
R = Gulf Prod. Co., McFadden No. 2
S = Rycade Oil Corp., McFadden No. 1

On the south, the Gulf Production Company's McFaddin No. 4 struck salt at 1,684 feet and abandoned the well at 1,787 feet. On the west, salt was struck at 2,000 feet. None of the salt wells have been so located as to give accurate data concerning the slope of the sides of the salt cores, but the differences between the depths at which the edge salt wells struck the salt, and the depths to which the wells not far out from the edge of the salt went without striking the salt, indicate that the slope must be steep (Fig. 3).

The cap at Spindletop is a disklike mass of anhydrite-gypsum and limestone (dolomite) which rests on the top of the salt but does not completely cover it. In the center of the field, in Higgins No. 3, the top of the cap was found at a depth of 886 feet (270 m.) and the cap was 761 feet (232 m.) thick; in Higgins No. 7, the top of the cap was found at a depth of 704 feet (214 m.). About 600 feet west of Higgins No. 7, in the Southern Company's No. 4, the top of the cap was encountered at 982 feet (298 m.) and 2,400 feet (720 m.) west at 1,210 feet (368 m.) About 2,500 feet (750 m.) north-northeast of Higgins No. 7, the top of the cap was at 1,095 feet (333 m.). In Higgins No. 2, 1,500 feet (450 m.) south of Higgins No. 7, the top of the cap was reached at 995 feet (303 m.). Toward the edge of the dome on the south and southwest, the cap seems to be missing. The cap, therefore, seems to be highest over the center and to slope away in all directions. As the top of the salt seems to be comparatively flat, the cap is apparently thickest in the center.

The anhydrite-gypsum portion of the cap is not well known. As is characteristic of the cap rock of the Gulf Coast salt domes, the anhydrite and gypsum form the lower part of the cap, and rest on the salt. Few of the wells were drilled through the limestone into the anhydrite and gypsum. The scanty data available in regard to them, are given by Hayes and Kennedy, and by Fenneman. As anhydrite is commonly reported as "gyp" by the drillers, the proportions between the anhydrite and gypsum are not known.

The limestone (dolomite) of the cap forms a cover extending over the anhydrite and by some is called "the cap" in contradistinction to which an anhydrite-gypsum cap is called "false cap." (Fig. 4). At the sulphur mines, the upper, barren portion of the limestone is called the "cap." Salt-dome geologists speak of the whole mass of exogenous rock capping the salt as the "cap." At Spindletop the limestone of the cap was identified in the early days as dolomite and has always been so designated. The following analysis of Spindletop cap rock, however, shows only a trace of magnesium, and the only sample of the "dolomite" from Spindletop that the senior writer has seen, as well as all the samples of limestone from the cap of other domes, effervesced in cold dilute hydrochloric acid. Much at least of the dolomite therefore seems to be limestone.

The most striking characteristic of the rock is its extreme porosity. During the gushing of wells, rock fragments varying in size from a fraction of an inch to the diameter of the casing have been blown to the surface. These always have a porous texture and even their most compact portions are shown, under the microscope, to

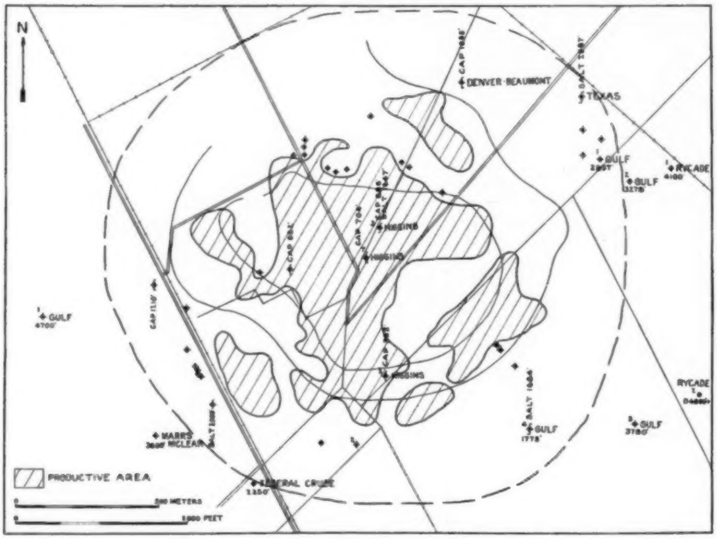

FIG. 4.—Map of Spindletop showing productive area, well data, contours on surface mound, and the — 3,000-foot (900 m.) contour on salt.

NOTE.—Rycade No. 2 marked as drilling at 4,800 feet has been abandoned at 5,400 feet, and the Rycade Oil Corporation has abandoned an additional dry hole at 3,962 feet, which should be about 1,400 feet north of the Gulf 4,700-foot dry hole.

contain a large proportion of vacant space. By the workers in the field the rock is compared to light-colored maple sugar. In addition to the minute spaces between the crystals, the rock itself contains many large cavities. The maximum size of these cavities cannot be determined, but many drillers report instances of the tools dropping several feet after passing through the outer crust of the rock. Considering the volume of oil recovered from the rock, the porosity must

exceed 33 per cent, or oil must have come in from an entirely unknown source. This high porosity combined with the high gas pressure explains the enormous yield of the early gushers.

Native sulphur is reported to be an important accessory mineral in the cap and in the beds immediately above the cap. In blow-outs and in gushers, large pieces of pure sulphur, crystals of sulphur an inch or more in length, chunks of mixed limestone and sulphur, and chunks of sulphur mixed with sand and clay have been blown out of the wells. In Heywood No. 3, sulphur rock was reported from four horizons, the lowest of which rests immediately on the oil rock. In a number of other wells, sulphur was reported in beds 5–45 feet

TABLE I*

ANALYSIS OF SPINDLETOP LIMESTONE CAP ROCK

Silica	0.40
Oxide of iron / Oxide of alumina	0.50
Lime	54.89
Magnesia	trace
Sulphur—as free sulphur and in organic combination	1.58
Sulphur—as sulphuric acid in combination	0.21
Carbonic acid	42.45
Total	100.03

*Analysis by S. H. Worrell, quoted by Fenneman, *U. S. G. S. Bull. 282* (1906), p. 27.

($1\frac{1}{2}$–13 m.) thick immediately above the oil rock. In those horizons, the sulphur was found mixed with sand, clay, or, in some cases, limestone. Some sulphur, the amount of which was not specified, was found in the oil zone, but not so much as below the oil zone. As few wells have been drilled below the top of the oil zone, not much is known in regard to the lower sulphur zones. In the sulphur domes, the main zone of enrichment is the zone of contact between the limestone and the anhydrite gypsum. The sulphur in the cap rock at Spindletop is reported to have been in the form of pure sulphur filling cracks and cavities in the rock and as crystals lining cavities in the oil-bearing rock.

The beds surrounding the salt core and the cap consist predominantly of sands and clays and minor amounts of gravel, calcareous

sandstone, and possibly a little limestone. On the top of the dome, the beds above a depth of 500 feet (150 m.) are composed almost entirely of sand and gravel, and the beds from this depth to the top of the cap are composed largely of clay, though "lime" is reported in beds 1–2 feet thick; in the Denver-Beaumont well, a 27-foot bed of lime was encountered that took seventy-five days to drill through. On the flanks of the dome, the upper zone of sand and gravel is 1,000 feet (300 m.) thick; between depths of 1,000 and 3,000 feet (300–900 m.) the section is composed predominantly of clay. Immediately below a depth of 3,000 feet, there are a few hundred feet of sand, sandstone, and calcareous sandstone below which are sands and clays. On the basis of lithology, a fair correlation of beds is possible across the dome and shows a gentle doming of the base of sand and gravel zone in conformity with the top of the cap. The wells on the flanks are so few and so scattered that it is not possible to work out the structure of the surrounding beds. From the Gulf Production Company's McFaddin No. 2 to the Rycade Oil Corporation's McFaddin No. 1 there is apparently a dip of about 50 feet in a distance of 500 feet. The base of the sand and gravel zone has suffered relative uplift of around 500 feet (150 m.) over the center of the dome in comparison to its position in the flank wells.

Stratigraphy.—The stratigraphic section as determined largely from the outcrop of the formations farther north is as follows:

The following section was found in the Rycade Oil Corporation's McFaddin No. 2:

Beaumont Clay
- Lissie
- Citronelle

Miocene
- Re-worked Cretaceous was identified from 1,800 to 3,915 feet (548 to 1,185 m.)
- Re-worked Cretaceous and re-worked Middle Oligocene at 3,932 feet (1,195 m.)
- No fossils in cores at 4,019, 4,057, 4,108, 4,128, 4,158, 4,166, and 4,172 feet
- Re-worked Cretaceous in cores from 4,187 and 4,211 feet (1,273 and 1,280 m.)

Non-fossiliferous zone with cores at 4,220, 4,230, 4,248, and 4,391 feet

Oligocene
- Discorbis zone at 4,508 feet (1,370 m.)
- Oligocene core at 4,694 feet
- Non-fossiliferous cores at 4,790 and 4,816 feet

The top of the Oligocene according to the section worked largely from the outcrop should lie at a depth of 1,300 to 1,400 feet (390 to 420 m.) In the Rycade Oil Corporation's McFaddin No. 2, the top of the Oligocene was actually at a depth of about 4,300 feet. Since in the position of this well beds at 4,300 feet should be much uplifted, the normal position of the top of the Oligocene should be at a much greater depth. The section above the Oligocene, therefore, shows a

TABLE II

Formation	Lithologic Character	Feet	Meters
Pleistocene Beaumont clay...........	Clay with silts and sands-marine	40	12
Pleistocene Lissie formation......... Pliocene Citronelle formation.....	Sands and gravels with some clay; non-marine chiefly	1,000 250	300 75
Miocene Pascagoula clay.........	Clays with a few lenses of sand and sandstone—Marine and non-marine Fleming Formation	300	90
Oligocene Hattiesburg clay........	Non-marine clays with thin layers of sand and sandstone	350	105
Catahoula sandstone......	Non-marine sands, sandstones, clays, and fine conglomerates	475	142
Eocene Jackson formation........	Marine marls, clays, and thin beds of sandstone	500	15
Yegua.................	....	800	240

thickening of at least 3,000 feet (900 m.) and probably over 4,000 feet (1,200 m.).

ORIGIN OF THE DOME

Various theories have been advanced in the past to account for the formation of the salt domes. Among the American geologists not familiar with the more recent descriptions and discussions of the German and Roumanian salt dome, many of these theories still have considerable vogue. In the light of the knowledge now available in regard to the German and Roumanian domes,[1] and more especially

[1] See Erich Seidl, "Preuss. Geol. Landesanstalt," *Archiv für Lagerstähenforschung*, Heft 26 (1921). The abundant sections illustrating this paper can be understood readily by persons familiar with only a few words of German.

the former, there seems to be little doubt that the salt domes are the result of plastic yielding of pre-existent sedimentary salt formations to deformation. In view of the slight knowledge actually in existence in regard to the salt of our American domes, it is not strange that distinct evidence of the sedimentary origin of the salt has not been observed. Many of the domes on which the drilling has been well placed show distinctly the great upthrust of the salt, as evidenced by the way it has dragged up the adjacent sediments with it. On account of the scattered spacing of the wells on the flanks of the dome, those relations are not well shown at Spindletop.

ORIGIN OF THE CAP

The more probable alternative hypotheses for the origin of the cap are: (1) that it is sedimentary limestone which has been pushed up ahead of the rising salt mass and which has been largely altered by sulphate waters; (2) that it is sedimentary anhydrite which has been pushed up ahead of the rising salt mass; (3) that it is a secondary deposit resulting from the precipitation of calcium sulphate of vadose sulphate waters coming in contact with the highly saline waters surrounding the salt dome; (4) that it is residual material which has been left behind in the solution of the salt.

The cap of the German domes is rather generally held by the German geologists to be residual. This theory seems to be the least probable of the four for the American cap rock but it is not impossible. The evidence in regard to the origin of the cap rock of the American salt domes is rather conflicting. At Spindletop the thick disk-like cap, not completely covering, or projecting beyond the top of the salt, has the form, size, and position of a block uplifted by the salt. The absence of the cap on the southern edge of the dome would demand explanation, if the cap were a secondary deposit formed in place, or if it were a residual deposit formed in place. As the upthrust of the salt core well may have been periodic, the fact that the cap has been upthrust into its present position is not evidence that it did not form in place at greater depth.

AGE OF THE DOME

The upthrust of the salt core to form a salt dome presumably is a long slow process which extends through several geologic periods.

The deformation of the late Pleistocene plain indicates upthrust due to upthrust of the salt core or to hydration of the anhydrite of the cap of gypsum. The inrusion of the salt into the Miocene indicates that the salt itself is older than Miocene and that a part of the intrusion is later than early Miocene. The salt itself carries no evidence of its age, either at Spindletop or on any of the other domes. At some domes, as, for example, Damon Mound, it is possible to determine that much upthrust had taken place by the beginning of Miocene times, but at Spindletop no evidence is available in regard to upthrust before Miocene times. From anology with the other domes, it seems probable the upthrust began well before the beginning of Miocene times. On none of the domes is there recognizable evidence of the time of the first distinct upthrust.

OIL AND GAS

Indications.—The indications which led to the drilling at Spindletop were the mound, gas seeps, and sour waters. Although indistinct, the mound is and was a marked feature of its region. By placing a bottle over a gas seep and getting an accumulation of reduced sulphur, Captain Lucas demonstrated that the gas was in part at least sulphur bearing. The sour waters were found both in springs and in shallow wells. Oil seeps have been reported, but this report has been denied by men familiar with the field in its early days. Paraffine dirt was not reported, but was not known in the early days and, if originally present, would later have been obscured by the development.

Occurrence.—Gas was originally present in rather moderate amount in all the oil sands and in gas sand just above the main super-cap sand. The gas from this sand is said to have caused the most destructive blow-outs at Spindletop. Although blow-outs from various horizons were common, and although the gas was under great pressure, the amount of the gas in all cases was apparently small, as the blow-outs did not last many hours.

Oil was found pretty much through the lower part of supercap section and in the top of the cap. The first oil at Spindletop was obtained by Captain Lucas at 575 feet (172 m.). The main productive horizon in the super-cap beds was a sand lying at a depth of 710 to

850 feet (213 to 255 m.) and at a distance of about 120 feet (36 m.) above the top of the cap. This "sand" was neglected in the early days in the rush for the big production in the cap, and attention came to be paid to it only after the waning of that production. The main productive sand, the one from which most of the production of the field was obtained, was the top of the cap. The oil was contained in the pores of the porous limestone and in the fissures and caverns in it. The wells had to go only a short distance into the limestone to tap the oil. The top of the limestone was at a depth of around 900 feet (270 m.) below the surface in the center of the field, and 1,000 to 1,100 feet (300 to 330 m.) below the surface on the edge of the field. A considerable part of the production is still obtained from the cap. Although numerous shows of oil have been obtained from supercap sands, there has been little or no production from them, except that from the sand at from 710 to 850 feet (213 to 255 m.).

Character.—Most of the gas at Spindletop was a wet petroleum gas containing a large amount of hydrogen sulphide. The combination of H_2S and the petroleum vapor had a very poisonous effect on those inhaling it in even moderate quantities, and "gassing" of the oil-field workers was a common experience at Spindletop in the early days; some deaths occurred from the gassing, but in most cases the men were merely temporarily "knocked out," and came to themselves or were resuscitated. The eyes seemed particularly susceptible to the effects of the gas, and gassed eyes was a common and painful ailment of the oil-field workers. The gas from the gas sand was a dry gas and was of a harmless nature.

The Spindletop oil is a dark-green to brownish oil with a Baumé gravity of 21–23°. On refining it yields, according to Fenneman:

	Per Cent
Gasoline	1.8
Kerosene	17.1
Solar	15.4
Lubricating	52.2
Asphalt	7.5

A similar-appearing oil with a gravity of 22.2° Baumé was obtained from the Rycade Oil Corporation's McFaddin No. 1, at 3,895 feet (1,122 m.).

Production.—The total gauged production of oil from the Spindletop field to January 1, 1924, has been 47,091,054 barrels (7,195,780 metric tons). On account of wasteful handling and lack of storage in the early days, enormous quantities of oil were lost. The amount of oil thus not accounted for is impossible of accurate estimation, but must have been enough to bring the figure for the total

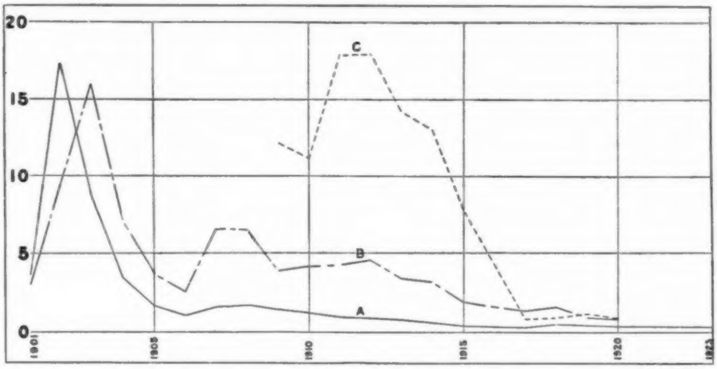

FIG. 5.—Production curves of Spindletop Oil Field.

A, yearly production of field in millions of barrels:

B and C, yearly production, respectively, of two leases in hundred thousands of barrels.

production of the field to well over 50,000,000 barrels (7,500,000 tons) (Fig. 5). The figures for the total yearly gauged production of the field are as follows:

	Barrels Net	Metric Tons
1901	3,593,113	538,750
1902	17,420,949	2,612,100
1903	8,600,905	1,289,620
1904	3,433,842	514,870
1905	1,600,379	239,960
1906	1,075,755	151,300
1907	1,615,513	242,230
1908	1,747,537	262,030
1909	1,388,170	208,140
1910	1,182,436	177,290
1911	965,939	144,830
1912	822,916	123,390

(*Continued on page 610*)

	Barrels Net	Metric Tons
1913	716,374	107,413
1914	580,130	86,985
1915	388,266	58,217
1916	340,441	51,046
1917	308,039	46,187
1918	502,265	75,310
1919	458,680	68,774
1920	323,995	48,580
1921	321,080	48,143
1922	295,015	44,235
1923	309,315	46,379
Total	47,991,054	7,195,779

It is interesting to notice that of the production 63 per cent was produced in the first three years of the life of the field. Spindletop's production of 17,420,949 barrels (2,612,100 tons) in one year has been exceeded in the Gulf Coast only by Humble, which produced 18,066,428 barrels (2,708,850 tons) in 1905.

The yearly production of representative leases has been, respectively, as follows:

	Barrels Net	Metric Tons
1901	299,579	44,920
1902	852,229	127,780
1903	1,604,884	240,640
1904	708,246	106,190
1905	370,388	55,540
1906	255,574	38,320
1907	657,326	98,560
1908	646,825	96,980
1909	390,569	58,560
1910	423,035	63,430
1911	422,726	63,380
1912	456,854	68,350
1913	337,035	50,530
1914	313,620	47,020
1915	192,870	28,920
1916	163,390	24,500
1917	142,390	21,350
1918	156,601	23,480
1919	94,323	14,140
1920	85,085	12,760
Total	8,572,550	1,285,364

	Barrels Net	Metric Tons	Wells
1909	12,136	1,820	2
1910	11,151	1,670	2
1911	17,813	2,670	2
1912	17,943	2,690	2
1913	14,270	2,140	2
1914	12,998	1,950	2
1915	7,890	1,180	2
1916	4,287	640	2
1917	844	137	2
1918	972	146	2
1919	1,216	182	2
1920	901	135	2
Total	102,420	16,460	

1906	19,221	2,880	4
1907	58,805	8,820	6
1908	26,210	3,930	4
1909	43,964	6,590	4
1910	30,139	4,520	4
1911	18,831	2,820	3
1912	8,926	1,340	3
1913	4,110	620	2
Total	210,207	31,520	

The per acre production at Spindletop is one of the highest for the Gulf Coast. The very sharply delimited productive area amounts to 265 acres. With a total production to date of fifty million barrels, the per acre production for the whole field is 190,000 barrels (28,500 tons). The average per acre production for the better fields on the Gulf Coast is about 50,000 barrels (7,500 tons), but in the case of most of the fields, the total productive area includes considerable territory of very poor productivity, and if in these cases only the main productive area is considered, the per acre production is much higher. The per acre production for the old or SE field at West Columbia up to January 1, 1921, was 123,000 barrels (18,400 tons) and, on the basis of the writers' estimate at that time of the future production, the ultimate per acre production of the SE field would be of the order of 200,000 barrels (30,000 tons). The per acre production at Jennings has been 209,000 barrels (31,340 tons) for the

whole productive area and 306,000 barrels (45,880 tons) for the main productive area. Of the other Gulf Coast fields the shallow or cap rock field at Humble is the most similar to Spindletop. The total cap-rock production there has been about the same as at Spindletop, but the productive area is seven times as great and the per acre production is only 30,000 barrels (4,500 tons).

The total number of wells drilled has been about 2,050, or on the average of about six wells per acre. Spindletop holds the record for the Gulf Coast Oil fields and for the oil fields of the United States for gusher production. The production of the Lucas No. 2 (the Lucas gusher) was variously estimated at 75,000 to 125,000 barrels (11,250 to 18,740 tons) per day. That of the Heywood Brothers No. 2 was estimated at 96,000 barrels (13,490 tons) per day. By gauge of its flow into a tank, it is said to have flowed 8,000 barrels (1,200 tons) in two hours. Within ten months it had produced 1,395,000 barrels (209,200 tons) of oil. There were only these two enormous gushers, but in addition to them there were many large wells. Although the data in regard to the early wells is very scanty, it is known that the Guffey and Gailey Oil Company completed five large wells on their Gladys City lease with initial production as follows: No. 7—15,000 barrels (2,250 tons), No. 4—10,000 barrels (1,500 tons), No. 1—8,000 barrels (1,200 tons), No. 5—7,000 barrels (1,050 tons), No. 9—5,000 barrels (750 tons); that the Beaumont-Palestine Oil Company completed a 10,000 barrel (1,500 tons) well; and that the Hogg Swayne, the American Oil Company, and other companies completed big wells.

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THE BRYAN HEIGHTS SALT DOME, BRAZORIA COUNTY, TEXAS

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ABSTRACT

The Bryan Heights salt dome is located in southern Brazoria County, Texas, near the mouth of Brazos River and nearly due south of Houston. It is marked topographically by a low mound which rises about 25 feet above sea-level. The top of the salt is encountered at an average depth of about 1,100 feet. Formations of Quaternary and later Tertiary age overlie the dome, and as in the case of other Gulf Coast domes there are more or less steeply inclined Tertiary rocks surrounding the salt core. A sulphur-bearing cap rock is of chief economic importance, sulphur being mined by the Frasch hot-water process from depths of about 700 to 900 feet below the surface. Some deep drilling, to depths of more than 3,500 feet, has been undertaken on the flanks of the dome, but no commercial oil or gas has been encountered.

INTRODUCTION

Bryan Mound lies in the southern portion of Brazoria County, Texas, 3 miles south of Freeport and not more than 1 mile from the coast. The region around the mound is low, flat, marshy country of recent material and not more than 2 or 3 feet above tide-level. The greater portion is occupied by shallow lagoons, some of which are dry at low tide. The mound itself rises out of these marshes to an elevation of about 23 feet and covers an area of approximately 300 acres. Since operations have been in progress the surface of the mound has sunk about 2 feet. This subsidence has taken place mostly in the areas where numerous wells have been operated.

HISTORY

Attention was first called to Bryan Mound by S. F. Peckham in a report on "Petroleum," in the *Tenth Census*, 1880, where he says, "near the mouth of the Brazos River and in other parts of Texas, beds of asphaltum occur, evidently resulting from the decomposition of petroleum, but so far as I have been able to learn, they have no commercial value." He indicated the position of the mound on his map as a point at which petroleum and asphalt occurred. This statement may have had reference to seawax which is occasionally found on the neighboring coast, or to minute grains of what appears to be the same material

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occurring in the soil at different places. During the oil excitement of the year 1901, the J. M. Guffey Petroleum Company obtained a number of leases around and on the mound and commenced drilling. At a depth of about 900 feet the first well encountered gas and had an estimated daily flow of 6,000,000 cubic feet, mostly hydrogen sulphide. Attempts to control the gas flow were unsuccessful and the well was abandoned. Another well was drilled by the same company, and as this also proved valueless the field was abandoned.

Other parties acquired the leases subsequently and attempted to drill for oil, but in each case the operations proved fruitless, either on account of the pressure of water or gas, although the gas pressure had largely fallen off. Seven wells were drilled in this region prior to 1904, some of them being carried to depths exceeding 1,000 feet. During the course of this work the drill is reported to have passed through large deposits of lime and gypsum showing considerable quantities of sulphur, the sulphur being scattered mostly throughout the gypsum, though some was with the lime. These materials were encountered between 700 and 900 feet beneath the surface.

During these early years of exploration of the coastal regions, petroleum was the only product desired, all other minerals being passed almost unnoticed. With the failure of petroleum production, Bryan Mound was abandoned until some time in 1906, when H. T. Staiti, P. M. Granbury, L. Bryan, and associates incorporated a company for the purpose of prospecting this territory for sulphur. The company held leases on the McNeil and Arnold tracts, including the greater portion of the mound, and carried out some exploration by drilling. On the strength of the showing of sulphur obtained arrangements for sale of the property were made, but because proposed methods of obtaining the sulphur infringed patents on the Frasch process, the sale finally fell through. Additional prospecting was carried on, however, and in all some twenty-seven test wells were drilled. It was asserted that sulphur in greater or less quantities had been found in every one of these test holes, and that about 300 acres had been proved to be profitably sulphur-bearing.

About 1912, the property passed into the hands of Mr. Swenson and associates. These gentlemen, after drilling a number of prospect holes in which sulphur was found in fair quantities, installed a plant at a cost of about $200,000 for the purpose of obtaining the sulphur and preparing it for market. This plant was similar to that of the Union Sulphur Company at Sulphur Mine in Louisiana, in employing what is known as the hot water process. During the early portion of December, 1912, sulphur was brought up for a few days, but owing to slight defects in the machinery, work ceased for some months. During 1914 or 1915, work was resumed with a greatly enlarged plant, and since that time operations may be said to have been continuous.

TOPOGRAPHY

Bryan Mound consists of a slightly elevated mound having a slight slope toward the east and southeast, the highest portion of

the surface, about 24 feet above sea-level, lying near the western side (Fig 1). The easterly inclination of the surface coincides with that of the underlying beds; thus the top of the salt, although not very regular, shows a descent from an average depth of 1,138 feet along the western side to 1,152 feet along the eastern side of the mound.

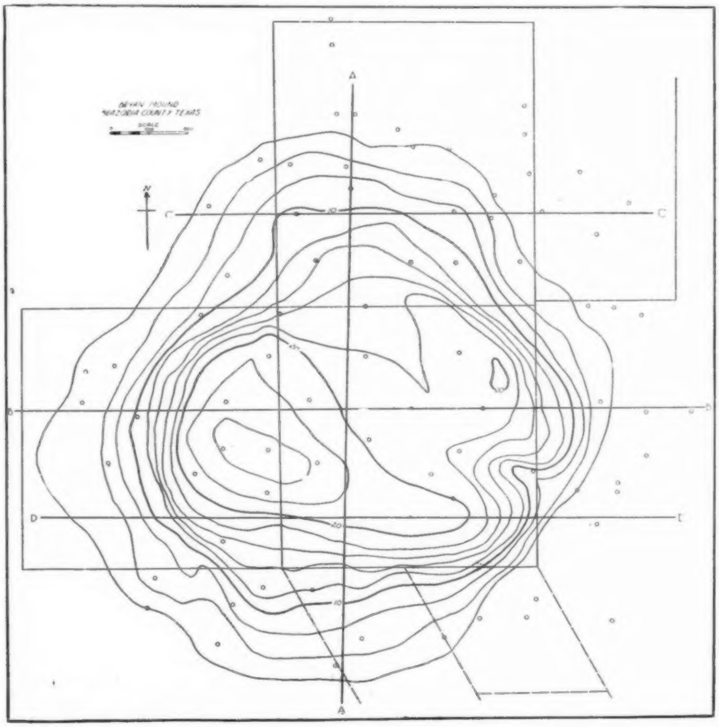

FIG. 1.—Surface topography of Bryan Mound, Texas. Contour interval 2 feet

This is a difference of only 44 feet in a distance of approximately 5,000 feet, a slope of 46 feet per mile. The gypsum- and sulphur-bearing formations show a similar easterly slope of 56 feet in the same distance, while the overlying limestones show a slope of 89 feet, or a dip of 94 feet per mile to the southeast. This is nearly four times the average slope of the surface.

GEOLOGY

Considered alone, the geology of Bryan Mound is comparatively simple, but in connection with its surroundings this mound presents a somewhat different problem. The rocks above the cap include about 300 feet of Recent and Pleistocene and Beaumont clays, and approximately 400–500 feet of sands and clays carrying Upper Miocene fossils. Since Pliocene formations occur along the flanks of some of the other mounds, notably at Stratton Ridge and Hoskins Mound, it is very probable that formations of this age also occur upon and around Bryan Mound, although nothing very definite is known about them.

Along the northern edge of the mound the country slopes somewhat gently toward the north for a short distance and drilling throughout that region has been carried down to depths ranging from 1,750 near Hawkinsville to 3,507 feet on the Bryan lease about 4 miles northwest of the mound. In another well drilled by the Chester Oil Company, about ½ mile east of the dome, the drill reached a depth of 2,911 feet. The Freeport Sulphur Company wells on the Poole & McNeil leases were carried down to depths of 3,000 feet.

Between West Columbia on the north and Bryan Mound on the south, there is evidently a trough about 3,000 to 3,500 feet deep. The materials filling this trough consist of clays, sands, shales, and gumbos with gravel and bowlders. From the presence of dark-green shale and sandy shale showing oil from 2,554 feet in the Chester well, the writer considers the lowest 257 feet as Fleming, and the uppermost 575 feet as belonging to the Beaumont clays. Some 1,400 feet of the intervening strata may be placed in the Lafayette and the rest in either the Lagarto or Lapara or both.

STRUCTURE

Dumble[1] has said that the Coastal Plain during Tertiary times was subject to oscillations which marked the dying out of vulcanism. Pliocene or pre-Pleistocene erosion acting in connection with flexures produced at the time left a number of hills and ridges scattered over the coastal strip which during the Pleistocene submergence were mostly covered by coastal clays.

[1] *Trans. Amer. Inst. of Min. Eng.*, Vol. 31, p. 1030.

Since no particular attention was paid to structural conditions when drilling was carried on, there is unfortunately no definite knowledge concerning underground conditions above the sulphur-

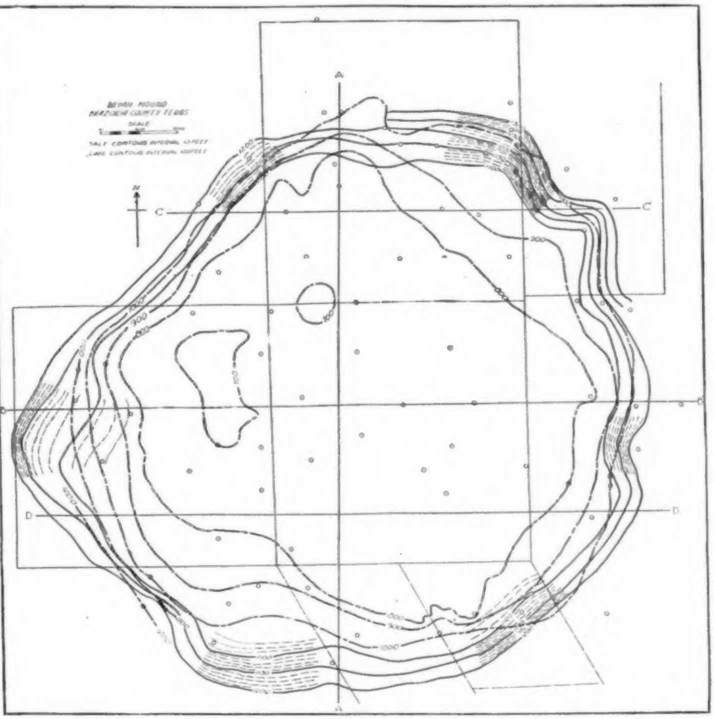

FIG. 2.—Topography of the top of the cap rock and the top of the salt in the Bryan Heights salt dome.

bearing beds, except that Upper Miocene and Pleistocene formations are present. However, since the Pliocene, Miocene, and Oligocene are present at Stratton Ridge, the salt dome nearest to Bryan, it is probable that these formations exist also at Bryan Mound, either above or around the salt core (Fig. 2).[1]

[1] Since this article was written, two wells have been drilled near the foot of the mound on the north side. The first, No. 616, was drilled to a depth of 1,956 feet and the second, No. 617, to a little below 2,550. No examinations were made of material

The structure of this mound is essentially similar to most of the coastal mounds. A series of sands, clays, and gumbos occurs down to about 700 feet; limestones, gumbos, and shales extend to 760 feet;

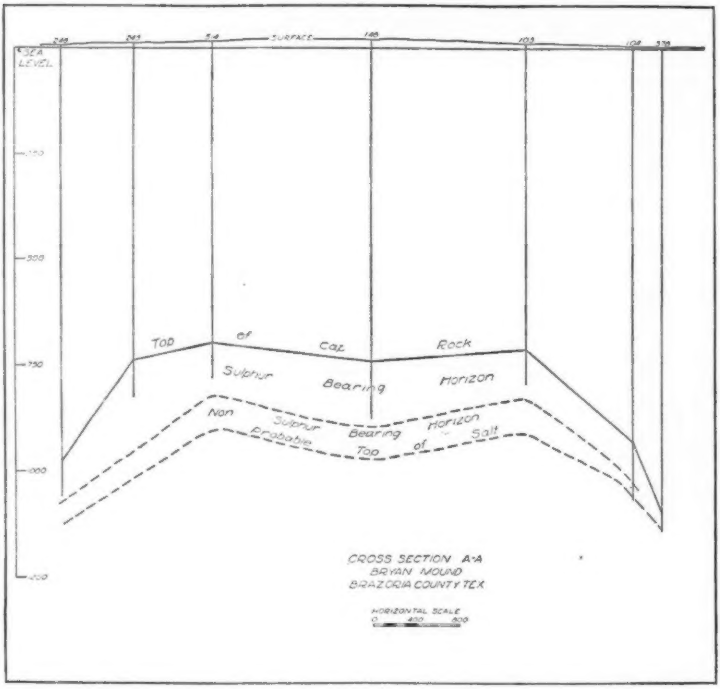

FIG. 3.—Cross-section from north to south across Bryan Heights salt dome. For location see Fig. 1.

to 1,090 feet there appears a zone of very porous, cavernous limestones and gypsums mixed with sulphur and carrying large quantities of hot sulphur water and hydrogen sulphide; below this and above the salt, there appears to be a series of limestones carrying

obtained from well No. 616, but numerous limestones were passed through from 1,626 feet to bottom. The cuttings from well No. 617 were examined by Mrs. E. R. Applin and Miss G. Newman of the Rio Bravo Oil Company and these showed the presence of both Miocene and Oligocene. This well also encountered limestones from 1,795 feet to bottom.

iron pyrite, gypsum, and sandstone, approximately 80 feet in thickness, but without sulphur. The salt makes its first appearance at depths between 1,000 and 1,100 feet.

Kirby Thomas, who examined a core from Reed well No. 3 drilled by the Gulf Development Company near the western margin of the dome, reports:

> This core shows 175 feet of sulphur formation of which 35 feet is limestone and gypsum showing sulphur estimated at less than 10 per cent, and 85 feet of gypsum and limestone with 10 to 50 per cent of sulphur; 54 feet of the core is missing, which indicates that the soft friable sulphur and gypsum in this much of the hole did not core. I examined all the 120 feet of core inch by inch and made an estimate that more than one-third would run 30 per cent or better, and that about 50 feet would run to about 10 per cent or better; about 20 feet was barren limestone.[1]

The beds encountered in a well drilled in the marsh northwest of the hill (Fig. 3) included heavy beds of clay of the Beaumont type and beds of quicksand. At 370 feet there was a small showing of gas, and fresh water occurs in a sand at the depth of 645 feet. *Gnathadon cuneatus* shells are common to a depth of 350 feet, but become scarce below that depth, although a few were found at a depth of 730 feet. Large quantities of wood in a carbonized condition are found at depths between 370 and 730 feet, but mostly from around 600 feet.

Dall reports that the fossils found in this mound between 649 and 668 feet are not older than Upper Miocene. In well No. 518 the following fossils identified by G. D. Harris were found between 292 and 300 feet: *Nassa acuta*, *Tornatina canaliculata*, *Arca transversa*, *Mulinia lateralis*, *Polynices duplicatus* (immature), *Terebra dislocata*, *Corbula contracta*, *Seila adamsi*, *Lucina amianta*, *Columbella obisa*, *Arca ponderosa* (immature). According to Harris, these are of Pleistocene age.

The sulphur-bearing beds consist mostly of gypsum in various forms from amorphous to crystalline. Selenite occurs as crystals and, less commonly, as thin plates or flakes. The amorphous gypsum is usually in a granular form and very intimately mixed with carbonate of lime. An examination of many of the cores from different wells shows the amorphous gypsum to be badly broken with very

[1] *Mineral Resources of U. S., 1912*, Part 2, p. 936.

close fractures extending in various directions throughout the core. These, although scarcely perceptible to the eye, all contain thin films of sulphur. It may be remarked that what has usually been considered as gypsum, closely associated and intermixed with the sulphur in this field, is not pure gypsum, since when treated with hydrochloric acid more than half of the rock goes off in the form of carbonate of lime, leaving a residue of gypsum in the form of a soft, white, pasty mass. At Hoskins Mound, it is claimed that at about the depth of 681 to 710 feet the drill passed through a soft, sticky, white clay, becoming chalky when dry. That description answers the residual mass left in the Bryan Heights sulphur-bearing beds after the removal of the lime and sulphur. The gypsum beds carry masses or thin deposits of black carbonaceous shales at somewhat irregular intervals and at different depths in the different wells. They also carry barite in small quantity and mostly in the form of rounded or water-worn nodules, some of which are as much as 3 inches in length and nearly 1 inch in thickness.

The structure of these sulphur-bearing deposits is not regular (Fig. 4). In some places, the selenite crystals stand at a high angle and at others lie in thin sheets almost flat; the granular portion of the deposits often shows threadlike columns standing perpendicular to the core of the well and again lying as if they had settled down quietly. The selenites sometimes show twinning, but this is not very frequent. The deposits might in some places be considered vesicular on account of the numerous cavities found interspersed between the thin layers of gypsum. In addition, numerous large channels are found in various wells. Neither of these cavernous conditions are universal throughout the mound.

The sulphur itself is very irregularly distributed throughout the beds. It is found often in very small crystals, even microscopic in size, but frequently in the form of larger masses of crystalline sulphur and as pipes extending upward through the beds. The sulphur is also found in the shape of stalactites in the openings made by the acidulated water or as thin plates lining the cavities made by the waters. While the sulphur sometimes appears as translucent crystals of a bright or pale amber color, the greater portion is amorphous,

showing a light-yellow or canary color. In whatever manner it may occur, it is always irregularly distributed and no two wells are alike as to content.

Immediately underlying the sulphur-bearing deposits and between these and the salt, there is a series of deposits consisting of

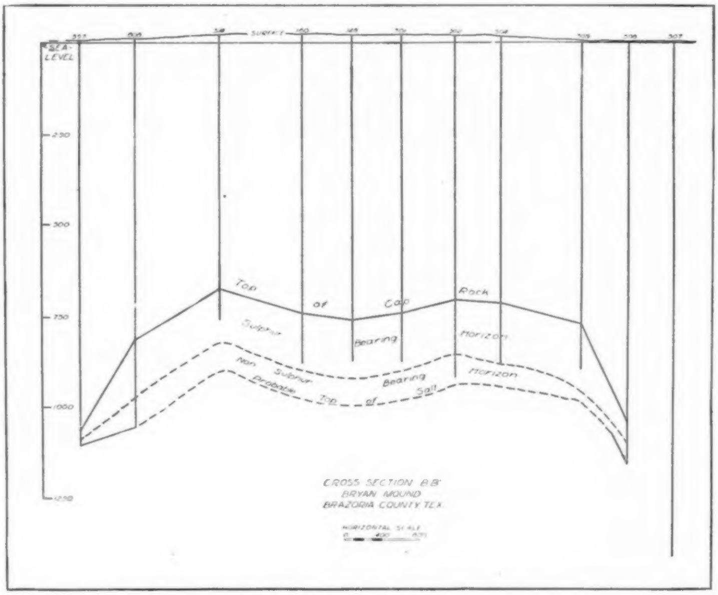

FIG. 4.—Cross-section from east to west across central part of Bryan Heights salt dome. For location see Fig. 1.

lime, anhydrite, and gypsum, with some gumbos and sand. These are reported to have an average thickness of about 80 feet, but it is doubtful whether this thickness can be found anywhere upon the surface of the mound itself. Limestone appears to be the prevailing material in this series. Across the northern end of the mound, a fine, loose sand appears in contact with the salt, and the same appears along the eastern side where 140 feet of mixed sand and salt are found in the bottom of well No. 586 (Fig. 5.)

On the western side of the mound many of the wells show the lime resting directly upon the salt. The barren zone between the sulphur-bearing horizon and the salt core of the mound is not constant in its character. Sand is frequently found in immediate contact

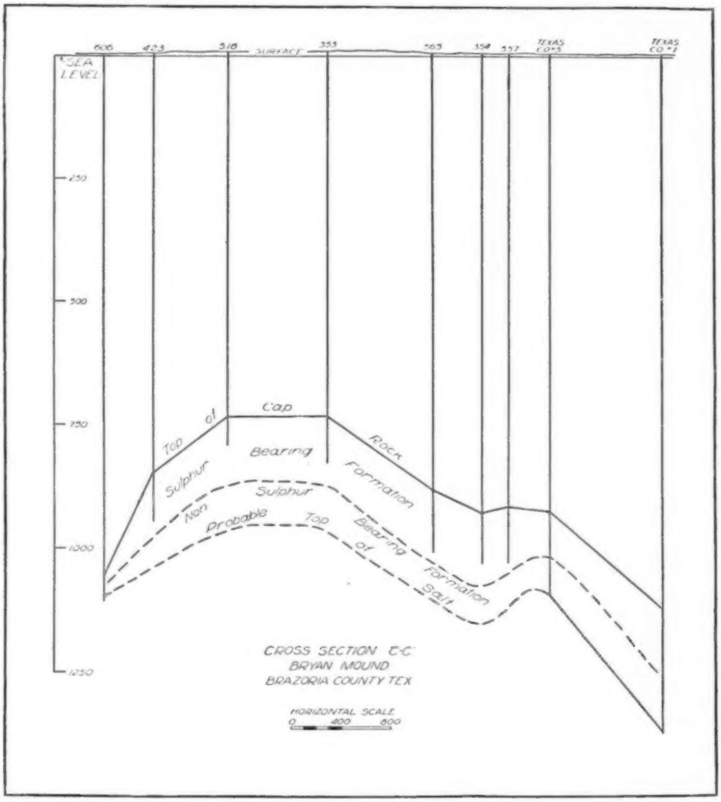

FIG. 5.—Cross-section from east to west across north part of the Bryan Heights salt dome. For location see Fig. 1.

with the surface of the salt, and in several holes gumbo occupies the zone of the gypsum or lime.

The following combination log of well shows the general character and arrangement of rocks at this mound:

	Depth in Feet	
Sands, clays, and gumbo	0	680
Blue limestone and gumbo with showing of oil	680	762
Gypsum with sulphur, cavernous with showings of gas and large quantities of black sulphur water	762	791
Gypsum and sulphur, about 75 per cent of the sulphur in the form of flakes; contains gas and black sulphur water	791	856
Gypsum and sulphur with gas	856	1,090
Soft formation, gypsum (anhydrite) and sandstone with some lime, no sulphur	1,090	1,112
Rock salt	1,112	1,160 plus

SALT

In keeping with the other coastal domes, salt forms the base of Bryan Mound. The thickness and general character of this salt deposit are unknown, since none of the drilling has gone more than 150 to 200 feet into it. One of the wells records the salt as being stratified, but that may be considered doubtful even though the core appeared to verify this statement.

Structurally, the salt is separated from the overlying sulphur-bearing gypsum by a series of deposits made up of hard, dark-colored gypsum (probably anhydrite), clays, dark shales, and in several wells by heavy deposits of sand, many of which appear to be intermingled with grains and crystals of salt. In some of the wells limestones lie directly upon the salt.

Although the upper surface of the salt shows a general slope from west to east, this gradient is very irregular as if the salt had been subjected to erosion before being covered by the overlying deposits. This condition is especially notable in the wells in which the sand was found on top of the salt. This sand with its associated salt grains lies in a pit or depression worn in the upper surface of the salt. The shales found in contact with the salt appear to occupy a similar position. Around the edge of the dome the cap rock drops down to the edge of the salt. Where the salt stops, this so-called cap-rock also stops (Fig. 6).

Around the west, south, and east sides, the salt has extremely steep slopes, in some places almost perpendicular. Along the western side this slope, although very steep, is greatly modified, but the strong slopes are again seen on the southeastern and northeastern sides. The sides of the dome as well as the top seem to have

been subjected to erosion before being covered up. This condition may, however, be due to an irregular uplifting of the salt core and an extrusion of the salt into softer deposits along the sides of the dome. A similar condition exists at Stratton Ridge and possibly

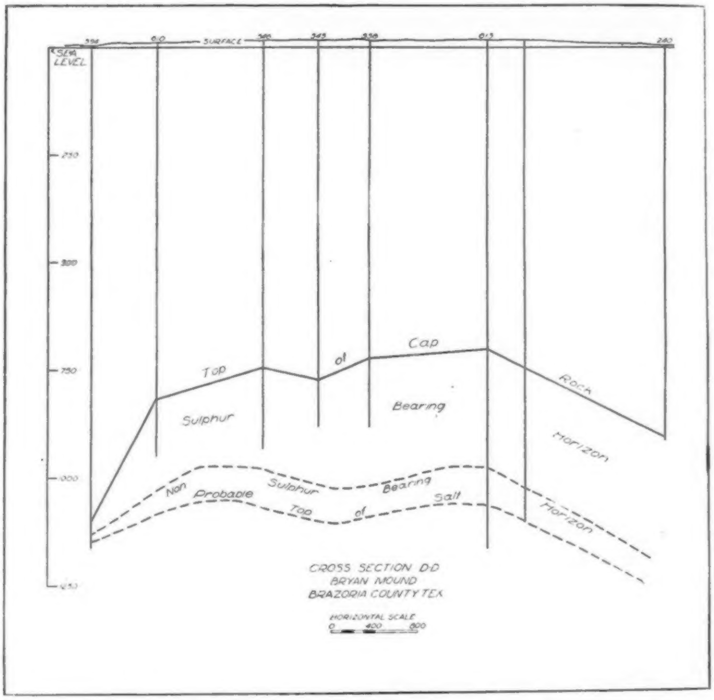

FIG. 6.—Cross-section from east to west across south part of Bryan Heights salt dome. For location see Fig. 1.

at Hoskins Mound. There is a possibility that a fault extends along the southern exposures of these three mounds and that this faulting is in a great measure responsible for the presence of the salt.

The salt has been subjected to considerable pressure. We know from the general geologic conditions of the coastal country that there has been great movement at different periods. It is probable that when pressure was exerted by these movements the areal ex-

tent of the original salt deposit was greatly reduced and the salt itself forced upward into the form of a mound as we now find it. The movements were repeated several times and the salt in all probability was subjected to pressure every time these earth movements occurred. The condition of the sides and upper surface of the salt accord with this view.

MINING METHODS

Economically, Bryan Mound may be considered only as a source of sulphur. The sulphur is recovered by the Frasch process, which was first utilized at the Union Sulphur Company's mine in Louisiana and has been described as follows:

In drilling these wells, the rotary rigs so common in the Gulf Coast oil fields are used. A casing is set in the well down to the cap rock which forms the top of the sulphur-bearing layer. Inside of this casing is set a 6-inch pipe perforated at the lower portion. Within the 6-inch pipe is a 3-inch galvanized iron pipe also perforated near the bottom and finally within that is a 1-inch galvanized iron pipe.

On operating the well hot water under a pressure of 200 to 300 pounds per square inch and at a temperature of 330 degrees F. is pumped down through the outer pipe and discharged into the porous sulphur-bearing calcite near the bottom of the strata. Similarly, hot water is forced down the 3-inch pipe and discharged into the porous formation through the perforated lower portion of the pipe. These two streams of hot water, at a temperature considerably above the melting point of sulphur (sulphur melts at about 240 degrees F.), gradually heat up the surrounding rock, melt the sulphur and its flows down into the heated area around the bottom of the well. After a sufficient heating has taken place the pumping of water down through the 3-inch pipe is discontinued and the melted sulphur rises in it. Air under high pressure is then pumped down the 1-inch pipe and the melted sulphur which has accumulated in the 3-inch pipe is lifted to the surface of the ground. This pumping of the melted sulphur by compressed air operates on the same principle as the air lift so commonly used for pumping water. The pressure of air required may run as high as 650 or 700 pounds per square inch in starting, but after the flow of sulphur is established the pressure drops off somewhat. The quantity of water required per ton of sulphur varies greatly with local conditions immediately surrounding the well.

The enormous quantity of water used in extracting the sulphur together with what we may consider as native water would in a very short time so flood the mound as to render it practically impossible to mine. As a relief, however, to this condition many of the old wells, from which all the sulphur available has been extracted, are utilized for the pumping of all surplus water. These wells are scattered throughout the mound and by this means the water found in the mound is kept under control.

OBSERVATIONS ON THE VERDEN SANDSTONE OF SOUTHWESTERN OKLAHOMA[1]

C. D. STEPHENSON
Tulsa, Oklahoma

INTRODUCTION

The Verden sandstone, named by R. D. Reed and M. Meland,[2] has attracted considerable discussion during the past two years by geologists working in the vicinity of Chickasha, Grady County, Oklahoma. The writer has observed this sandstone throughout an area extending from T. 2 N., R. 6 W., to T. 15 N., R. 12 W., all in southwestern Oklahoma. The recent areal geology map of the United States Geological Survey displays the location of these outcrops from T. 2 N., R. 6 W., to T. 8 N., R. 9 W., and the accompanying map shows additional outcrops north of this area. More exposures than are shown were reported by farmers living in Ts. 10 and 11 N., R. 9 W., but these reports have not been verified.

The writer wishes to acknowledge his indebtedness to Sidney Powers and Harry J. Brown for their criticism of this paper.

PHYSICAL CHARACTERISTICS

The lithology of the Verden sandstone has been described by Reed and Meland,[3] Frank Reeves,[4] and C. N. Gould,[5] and will therefore be but briefly described here. This formation is a coarse-grained, cross-bedded sandstone in which the quartz grains are rounded. The formation contains many fragments of angular white chert which weather into prominence. The cementing material is red, and makes up at least half of the rock. Reed and Meland[6] state that the cementing material makes up from 50 to 75 per cent

[1] Published by permission of C. J. Wrightsman, Wrightsman Petroleum Co.

[2] *Jour. Geol.*, Vol. 32, p. 151.

[3] *Op. cit.*, p. 152.

[4] *U. S. Geol. Sur. Bull.*, No. 726-B.

[5] *Bull. of Amer. Assoc. of Pet. Geol.*, Vol. 8, No. 3, p. 335.

[6] *Op. cit.*, p. 155.

of the rock, and is calcite. The Verden sandstone contains fossils which have been classified as marine.[1] In the Whitehorse sandstone and the Marlow shale no fossils have been observed by the writer. In Sec. 18, T. 4 N., R. 6 W., on a large slab of Verden sandstone which caps a hill, there are about ten well-preserved footprints apparently human. In addition to the footprints there are impressions resembling bear tracks and some large bird tracks. There is also an angular line similar to the pattern often seen on Navajo rugs. Probably all of these impressions are the carvings of Indians.

The most unusual feature of the Verden sandstone is its "shoestring" nature. From the southernmost exposure, in Sec. 13, T. 2 N., R. 6 W., to Sec. 33, T. 12 N., R. 9 W., a distance of some 70 miles, the formation is never more than 1,200 feet wide and is usually less. The formation is exposed in a series of buttes, following an almost straight line. The thickness of the sandstone is about 8 feet. At Greenfield, in T. 15 N., R. 12 W., where the formation is predominantly limestone, it has a maximum width of about 4 miles. By observing the hills on both sides of the outcrop throughout its course this narrowness of deposition is easily demonstrated.

STRATIGRAPHIC POSITION

From a point in T. 4 N., R. 6 W., to the exposure of limestone in T. 15 N., R. 12 W., the writer has carefully observed the stratigraphic position of the Verden sandstone, and has reached the conclusion that it rather definitely occurs about 35 feet below the base of the Whitehorse sandstone in Grady, Caddo, and Canadian counties. The counties in which this relation to the Whitehorse sandstone is noted are mentioned because it is possible that there is some confusion about the Whitehorse sandstone north of this area. Directly below the Whitehorse sandstone the Marlow shale is present. In the counties mentioned it has not been deemed advisable to subdivide the Marlow shale into the Dog Creek shale and Blaine gypsum with which it has been correlated.[2] The Verden sandstone lies in the Marlow shale. From a point in Sec. 19, T. 4 N., R. 6 W., elevation 1,245 feet, to the outcrop in Sec. 34, T. 8 N., R. 9 W., eleva-

[1] Frank Reeves, *op. cit.*, p. 61.

[2] C. N. Gould, *op. cit.*, pp. 331–35.

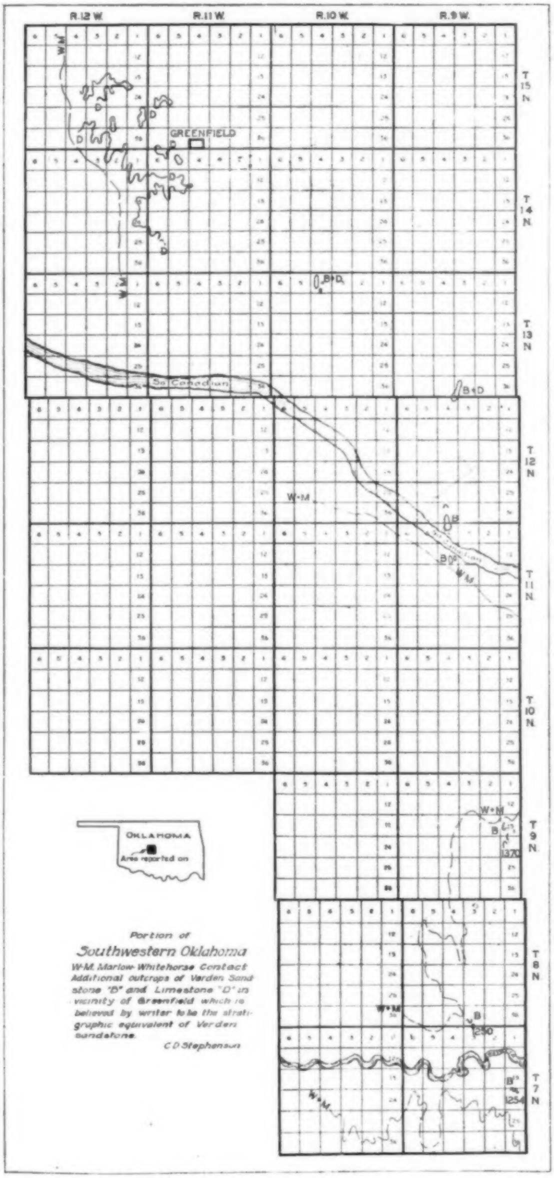
R.12 W.
R.11 W.
R.10 W.
R.9 W.
T 15 N.
T 14 N.
T 13 N
T 12 N
T 11 N.
T 10 N.
T 9 N.
T 8 N
T 7 N
GREENFIELD
So. Canadian
OKLAHOMA
Area reported on
Portion of
Southwestern Oklahoma
W-M. Marlow-Whitehorse Contact
Additional outcrops of Verden Sandstone "B" and Limestone "D" in vicinity of Greenfield which is believed by writer to be the stratigraphic equivalent of Verden sandstone.
C D Stephenson

FIG. 1

tion 1,250 feet, the Verden sandstone follows approximately the northwest strike, and elevations taken along its course show only minor variations with a minimum elevation of 1,220 feet on the south line of Sec. 11, T. 6 N., R. 8 W. Going north from the outcrop in Sec. 34, T. 8 N., R. 9 W. (1,250 feet), to the exposure in Sec. 13, T. 9 N., R. 9 W. (1,370 feet), the dip determined coincides with the normal southwest dip measured on other beds. In Sec. 9, T. 11 N., R. 9 W., and in Sec. 33, T. 12 N., R. 9 W., the formation holds the same postion below the Whitehorse sandstone. It should be pointed out that the contact between the Whitehorse sandstone and the Marlow shale can be located exactly in few places, but the approximate contact is one which is easily followed. Certainly no variation of more than 25 feet in the position of the Verden sandstone would escape detection.

THE GREENFIELD LIMESTONE

For many years the limestone capping the hills immediately west of Greenfield in Ts. 14–15 N., Rs. 11–12 W., has been called the "Day Creek" dolomite, but this correlation is incorrect since the Day Creek dolomite lies directly above the Whitehorse sandstone, and the limestone at Greenfield lies below the Whitehorse sandstone as defined by Reeves.[1] It is the writer's belief that the Greenfield limestone is the stratigraphic equivalent of the Verden sandstone. In Sec. 33, T. 12 N., R. 9 W., there is a typical exposure of Verden sandstone. In Sec. 34, T. 13 N., R. 9 W., just 5 miles north, the limestone which has been called the Day Creek makes its first appearance. At this point two thin beds of limestone appear, and between them are found sandstone beds, which, while not so coarse-grained, resemble the Verden sandstone. The exposure is about 1,500 feet wide. For this formation in Sec. 34, T. 13 N., R. 9 W., to be the Day Creek dolomite, the entire thickness of the Whitehorse sandstone, some 250 feet, would have to dip under from the typical Verden sandstone just 5 miles south. This does not occur, but rather one is on a typical Marlow shale from Sec. 33, T. 12 N., R. 9 W., to the limestone exposure in Sec. 34, T. 13 N., R. 9 W. The two exposures just referred to are critical in a consideration of the Green-

[1] *Loc. cit.*

field correlation, for having once gradually introduced limestone to the Verden sandstone one can more readily accept the rather marked change. The limestone at Greenfield can be readily shown to lie below the Whitehorse sandstone, and while having more width than is usual in the Verden sandstone, the characteristic narrowness of outcrop is present. In passing from the first limestone outcrop in Sec. 34, T. 13 N., R. 9 W., to the limestone hills west of Greenfield one is continually on the Marlow shale. The accompanying map shows the contact of the Whitehorse sandstone and the Marlow shale throughout a portion of this area.

A reference has been made to a possible confusion of the Whitehorse sandstone north of the area under discussion, and if such confusion is present it is connected with the miscorrelation at Greenfield. While the writer has not visited the exposure, from the description given it is believed that such a miscorrelation is probable in the limestone-capped hills at Watonga.

ORIGIN OF THE VERDEN SANDSTONE

Because of the lack of width exhibited by the formation and other features, the Verden sandstone has been generally thought to represent a river deposit. Reeves[1] suggested that a strong tidal current flowed upstream in a river which flowed southeast, while Reed and Meland[2] suggested that the stream headed in the vicinity of the Arbuckle Mountains and flowed northwest. They showed a close similarity between the heavy minerals of the Verden sandstone and the Simpson formation. The writer's work indicates that if the deposit is the result of a stream the direction of flow must have been to the northwest. One difficulty to be overcome in assigning this formation to stream deposition is the fact that the Verden sandstone holds very closely to one stratigraphic position. Present-day streams in degrading their courses cut down from one formation to another, and it is difficult to reconcile stream deposition throughout a hundred miles to one stratigraphic position.

CONCLUSIONS

This article has been written to call attention to three features of the Verden sandstone heretofore not mentioned in the literature:

[1] *Op. cit.*, p. 61.

[2] *Op. cit.*, pp. 166, 167.

first, the unquestionable northern extension of the formation; second, its consistent stratigraphic position; and third, the miscorrelation of the Greenfield limestone.

AUTHOR'S NOTE

Since the submission of the foregoing paper, the writer was present at the presentation of a paper by R. L. Clifton at the Convention of the American Association of Petroleum Geologists, March, 1925, on "Areal Extent and Stratigraphy of the Whitehorse Sandstone." It appears from this paper and from a conversation with Dr. J. W. Beede that at the type locality of Whitehorse Springs, Gould included a channel sandstone lying below a massive sandstone in the name Whitehorse. Gould[1] places the Verden sandstone in the Dog Creek formation. It appears, then, that more confusion exists than was indicated in the foregoing paper. It does not seem advisable to the writer to include two formations so dissimilar as the Verden sandstone, a channel deposit, and the massive Whitehorse sandstone, a blanket deposit 250 feet thick, under the same formation name. These two formations are separated by about 35 feet of shale, containing locally some gypsum beds. On the map accompanying the recent article by Gould, the area shown as Whitehorse sandstone does not include the area of the Verden sandstone outcrop. On the new United States Geological Survey areal geology map of Oklahoma the Whitehorse sandstone and the Verden sandstone are shown as separate formations. If, however, because of priority the name "Whitehorse" for these three formations has preference, it is here suggested that three divisions be made as follows: Upper Whitehorse, consisting of the massive, fine-grained, poorly-cemented sandstone about 250 feet thick. This Upper Whitehorse may be seen at many localities in southwestern Oklahoma, namely, near Rush Springs, T. 4 N., R. 8 W.; in the Cement oil field, Ts. 5 and 6 N., R. 9 W; and around the town of Hinton, T. 11 N., R. 11 W. The Middle Whitehorse would include the red shale and gypsum directly under the massive sandstone and above what has been called "Verden" sandstone. The Middle Whitehorse is exposed in the bluffs on the south side of the Washita River in T. 7 N., R. 9 W. The Lower Whitehorse would include the channel sandstone or its stratigraphic equivalent which locally has been called the "Verden" sandstone.

Under this division the limestone outcropping in Ts. 14 and 15 N., Rs. 11 and 12 W., would be Lower Whitehorse, and about 250 feet below the Day Creek dolomite with which it has been previously correlated by others.

[1] C. N. Gould, "A New Classification of the Permian Red Beds of Southwestern Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 8, No. 3, 1924.

THE LULING FIELD, CALDWELL AND GUADALUPE COUNTIES, TEXAS[1]

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Luling, Texas

ABSTRACT

The Luling field, in Caldwell and Guadalupe counties, Texas, is a fault structure located about 20 miles southeast of the main Balcones fault. The area is drained by San Marcos River. The Wilcox formation is exposed at the surface and the producing formation is the Edwards limestone of the Comanchean Cretaceous. The field is 7.5 miles long and averages about ½ mile wide. The discovery well was brought in on August 14, 1922. On December 31, 1924, there were 391 producing wells in the field.

The structure is a faulted monocline limited on the northwest, northeast, and southwest by faults of about 450-foot displacement. The strike of the structure is NE.-SW. The heave of the fault measured on the top of the Edwards is 1,000–1,800 feet. The highest points of the structure are near the two extremities of the field, the middle portion being about 40 feet lower. The sedimentary column seems to overlie a metamorphic basement composed of rocks of early Cretaceous or pre-Cretaceous age. The average depth of the top of the Edwards oil horizon is about 2,100 feet. The oil is of abou 27° Baumé gravity. The total production of the field to December 31, 1924, was about 14,500,000 barrels and the daily production about 30,000 barrels.

INTRODUCTION

The Luling field has the unique distinction of being the first important oil field in Texas that produces oil in commercial quantities from the Edwards limestone of the Comanchean Cretaceous. The writer has had opportunity to study the field in detail since the completion of the Caldwell County discovery well and to work out the northeasterly and southwesterly extensions. He is indebted to Robert L. Cannon for valuable aid in the study of the areal geology, and to Frederic H. Lahee and David Donoghue for helpful criticism and encouragement in the preparation of this paper. Vernon E. Woolsey and Roy A. Dobbins contributed much information relating to the subsurface geology and the production of the field. Sources of general information on the geology of the region are listed in the bibliography at the conclusion of the paper.

LOCATION

The field is located in the region of Lower Tertiary rocks, on the Gulf Coastal plain about 20 miles southeast of the main Balcones

[1] Published by permission of the United North and South Oil Company.

fault line. With reference to this fault its position is comparable to that of the Mexia-Powell and Somerset fields. It lies about $4\frac{1}{2}$ miles northwest of Luling, Caldwell County, and approximately on a line between Joliet, Caldwell County, and Kingsbury, Guadalupe

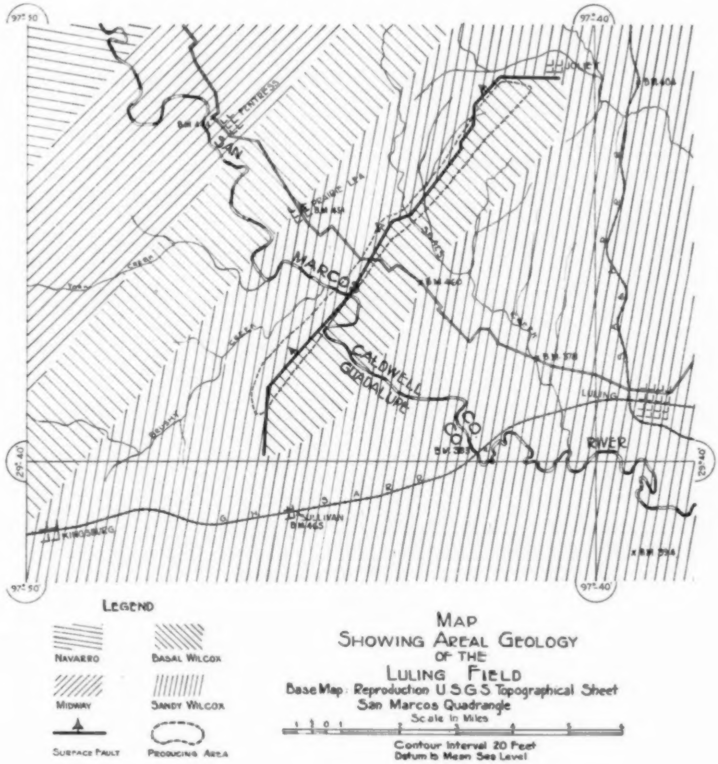


FIG. 1

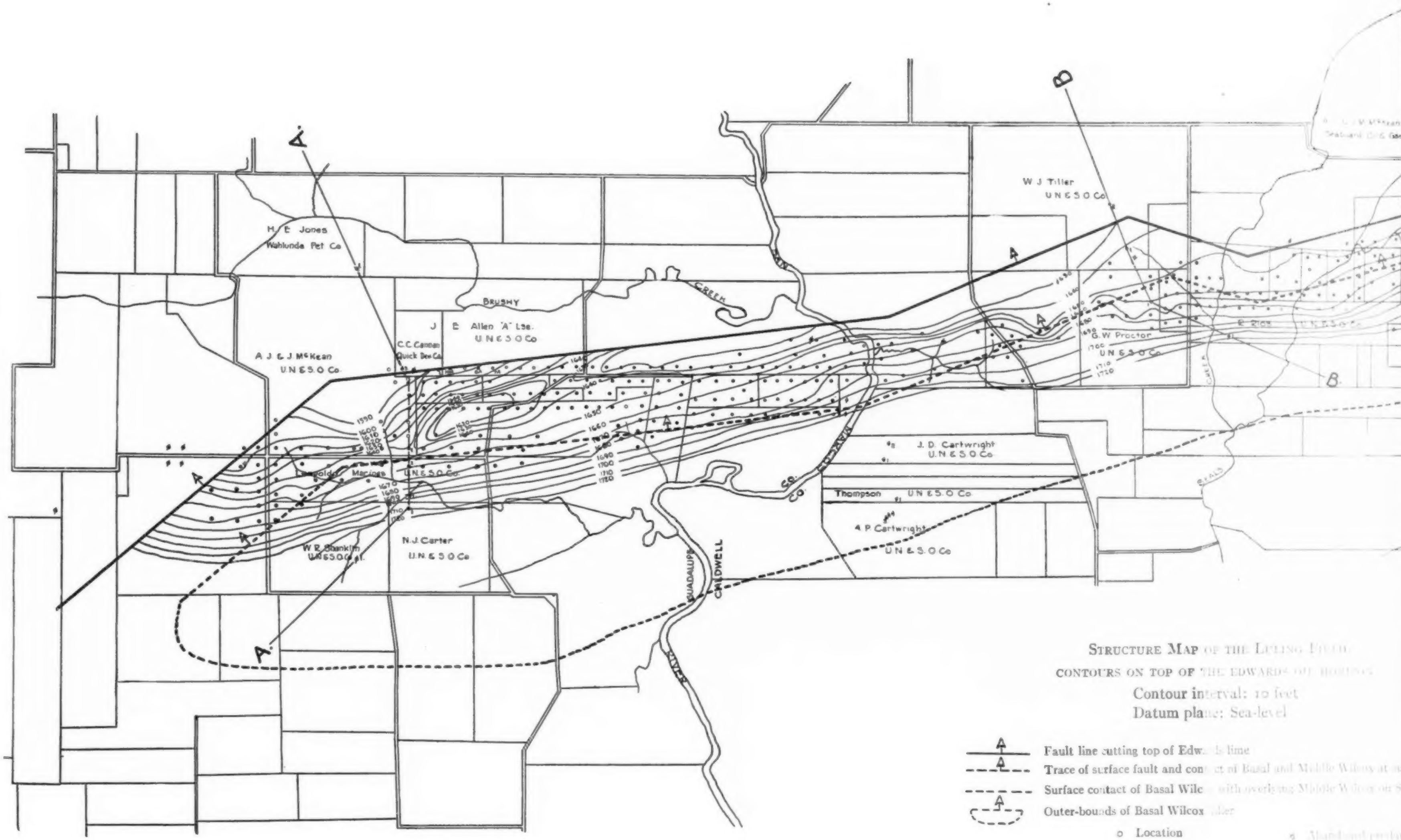
County. The length of the field from northeast to southwest is about $7\frac{1}{2}$ miles and its maximum width is about 3,000 feet. The field is accessible by improved roads from Luling, Caldwell County, the most convenient shipping point (Fig. 1).

HISTORY

The factor that led to prospecting with the drill in the Luling oil-field region was the northeast-southwest trending fault, which

Fig. 2.—Exposure of the Luling fault plane on San Marcos River

crosses San Marcos River southeast of Prairie Lea, Caldwell County. Credit for the discovery of this fault exposure (Fig. 2) and for the



Structure Map of the Luling Field

Contours on top of the Edwards

Contour interval: 10 feet

Datum plane: Sea-level

Fault line cutting top of Edwards lime

Trace of surface fault and contact of Basal and Middle Wilcox at surface

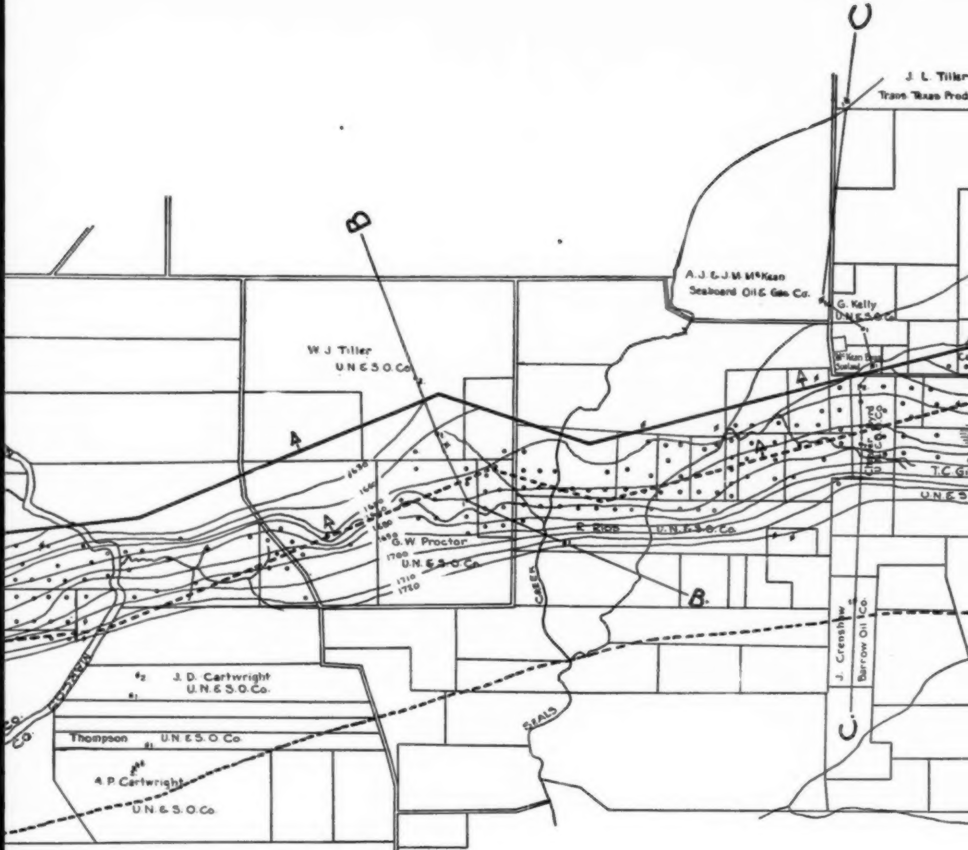
Surface contact of Basal Wilcox with overlying Middle Wilcox

Outer-bounds of Basal Wilcox

Location

Drilling

Producer



STRUCTURE MAP OF THE LULING FIELD

CONTOURS ON TOP OF THE EDWARDS OIL HORIZON

Contour interval: 10 feet

Datum plane: Sea-level

A Fault line cutting top of Edwards lime

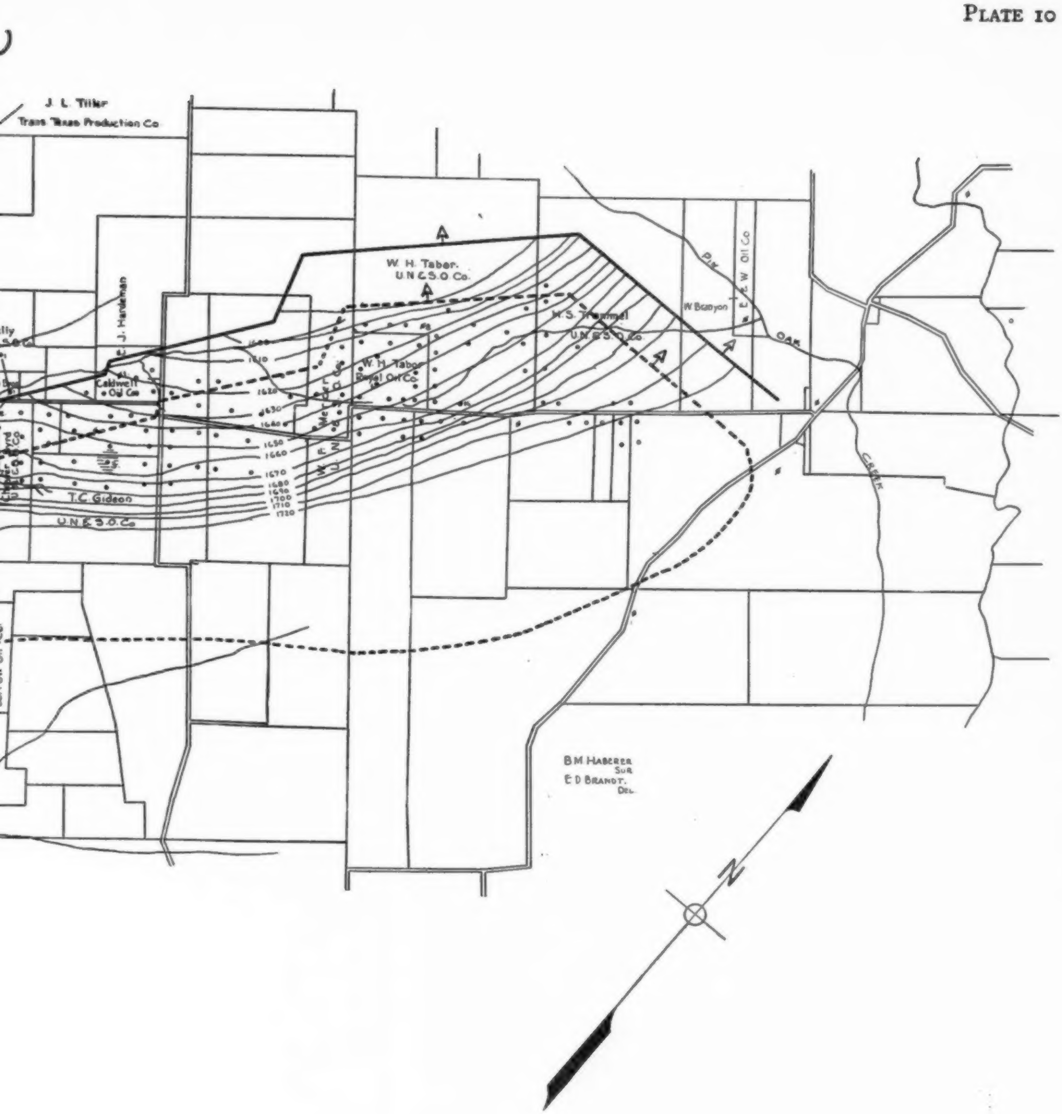
A Trace of surface fault and contact of Basal and Middle Wilcox at surface fault

Surface contact of Basal Wilcox with overlying Middle Wilcox on SE. flank

A Outer-bounds of Basal Wilcox inlier

- Location
- Drilling
- Producer
- Abandoned producer
- Abandoned dryhole
- Gasser

PLATE 10


J. L. Tiller
Trans Texas Production Co
W. H. Taber.
U.N.E.S.O. Co.
J. Hardeman
Caldwell Oil Co
W. H. Taber
Royal Oil Co.
H.S. Trammel
U.N.E.S.O. Co.
W. Banyon
E. & W. Oil Co.
PIN
OAK
CREEK
T.C. Gideon
U.N.E.S.O. Co.
1600
1610
1620
1630
1640
1650
1660
1670
1680
1690
1700
1710
1720
B.M. HABERER
SUR.
E.D. BRANDT.
DEL.
N

recognition of its geological significance belongs to Vernon E. Woolsey.

The Texas Southern Oil and Lease Syndicate in 1919 and 1920 acquired leases along the projection of this fault and drilled one well, Thompson No. 1, in Caldwell County at a point about $\frac{1}{2}$ mile southeast of this fault in the river. Oil shows were encountered in the Eagleford shales but the hole was abandoned at 2,044 feet. On March 18, 1921, this concern was succeeded by the United North and South Oil Company, Inc., and drilling was resumed in the Thompson No. 1 area. In Cartwright No. 1 oil showings were encountered in the Eagleford and in the top of the Edwards lime. Similarly, Cartwright No. 2 encountered favorable showings in the Edwards, but the locations were too far southeast of the fault to be commercially productive. Further drilling on the Cartwright lands resulted in failure to obtain production. However, on August 10, 1922, the discovery well was brought in on the Rafael Rios lease in Caldwell County, the oil being obtained from the top of the Edwards lime. The first notable extension to the northeast, the Caldwell Oil Company's Hardeman No. 1, was completed on March 13, 1923. It blew in as a gasser spraying about 500 barrels of oil. This was followed on May 23, 1923, by the completion of a 1,400-barrel well on the Royal Oil Company's Tabor 40 acres. The Hardeman well was located about 800 feet northwest of the recognized trace of the surface fault, whereas the Tabor well was located about 1,350 feet southeast of the trace of the fault. Upon the completion of the Tabor well, the field was proved for a distance of about $2\frac{1}{2}$ miles northeast of the Rios discovery well (Plate 10).

Following the completion of these extensions drilling became active and by December 31, 1923, some 90 producers had been completed. One of the most significant developments in the field during the year 1923 was the completion of the United North and South Oil Company Marines No. 1 in Gaudalupe County, an extension of nearly 4 miles southwest of the Rios discovery well. The Marines well was located about 800 feet southeast of the trace of the fault and came in as a 300-barrel producer. On December 31, 1924, the field had 391 producing wells.

TOPOGRAPHY AND DRAINAGE

The country about Luling is gently rolling agricultural land, with maximum relief of about 115 feet. The highest surface elevation of producing wells is about 488 feet above sea-level and the lowest 373 feet. San Marcos River, flowing in a southeasterly direction, controls the drainage of this area.

There is no conclusive evidence that the fault plane affects the courses of minor drainage channels. However, indurated beds on the northwest side of the fault resist erosion effectively enough to have caused the east fork of Seals Creek to flow in a southwesterly direction and Brushy Creek to flow in a northeasterly direction. The strike of the strata rather than that of the fault controls the directions of the two streams mentioned.

SURFACE GEOLOGY

The normal dip of the surface strata in the vicinity of the field varies from 1° to 2° to the southeast. The strike of the strata is, in general, parallel to that of the Balcones escarpment at the nearest point and approximates N. 35° E. Variations from the normal southeast dip are due to cross-bedding and structual deformation.

The surface beds belong to the Wilcox formation of Eocene age. Overlying the Wilcox beds in many places are flint gravels of Uvalde or Reynosa age, but in the area covered by the field these gravels are residual and do not occupy their normal stratigraphic position. In the Guadalupe County extension adjacent to San Marcos River the Wilcox beds have been eroded and covered with recent flood-plain silts and gravels. The thickness of these flood-plain deposits varies from a few feet to about 100 feet, their thickness diminishing in a southwesterly direction away from the river channel.

Due to displacement occasioned by the fault both the basal Wilcox and what is probably Middle Wilcox are exposed in the field. In general, the structure is expressed at the surface as a basal Wilcox inlier surrounded by younger Wilcox beds. The strata on the upthrown or southeast side of the fault are of basal Wilcox, whereas the strata on the downthrown or northwest side are of younger Wilcox, the latter being stratigraphically about 400 feet higher in the normal section (Figs. 1, 3, 4, and 5). At the northeastern ex-

tremity of the field, the basal Wilcox phase terminates. Due to an east-west cross-fault downthrown on the north Wilcox, sediments of younger age (probably Middle Wilcox) succeed the basal Wilcox phase near Joliet, Caldwell County. Similarly, at the southwestern extremity of the field, the basal Wilcox beds are succeeded by

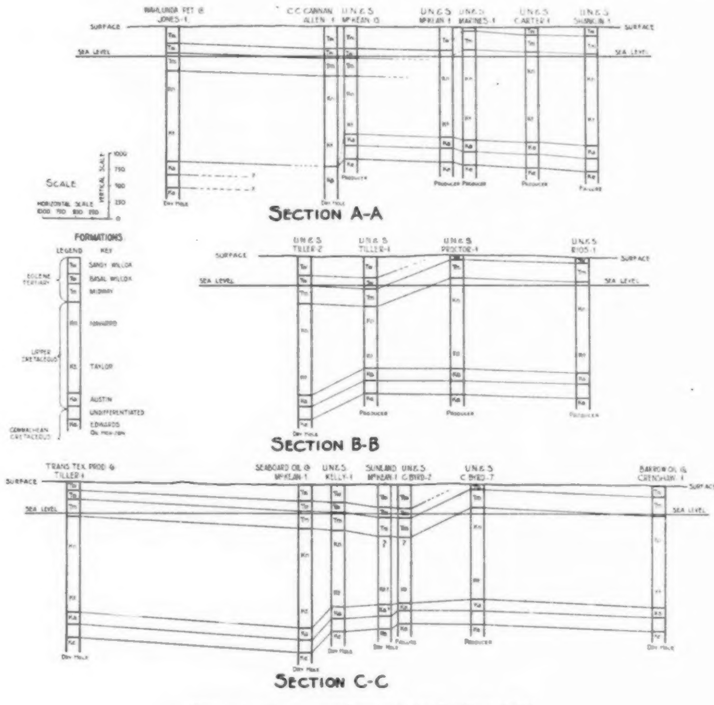


FIG. 3.—Cross-sections of the Luling field

younger Wilcox. Direct surface evidences of a cross-fault are not discernible at the southwest end of the field, but a careful survey of the surface geology reveals strong evidences of a structural "low" abutting the uplifted basal Wilcox beds. Borehole data have given additional proof of the structural depressions at the northeastern and southwestern extremities of the field (Plate 10). The sections

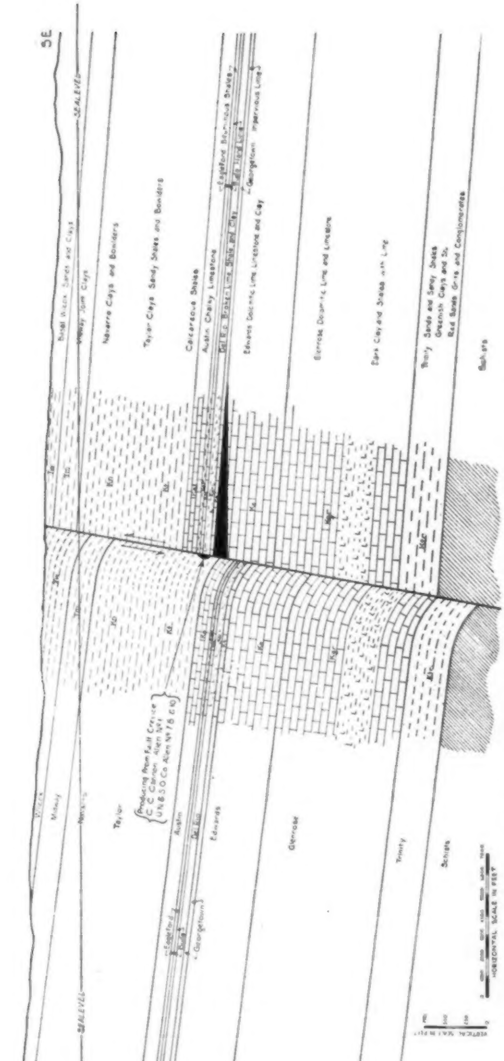


FIG. 4.—Generalized northwest-southeast section showing structure and stratigraphy of the Luling fault

shown in Figures 4 and 5 illustrate the sequence of the strata along the direction of the regional southeastward dip. The Midway-Wilcox contact is found about 3 miles northwest of the fault. (Fig. 1).

The basal Wilcox overlies the joint-clays of the Midway and consists of laminated fine-grained sands and clays, with clays predominating. Irregular zones of impure siderite bowlders are found in these beds. The basal Wilcox is characteristically argillaceous rather than sandy and weathers to reddish- and dark-brown clay soils. The predominant perennial vegetation consists typically of mesquite, post oak and blackjack being relatively scarce. Two easily recognized fossils are prominent in the fauna of these beds—*Venericardia planicosta?* and *Ostrea tasex?* The writer has found no pure limestone nor Foraminifera and petrified wood is apparently absent. The presence of marine fossils and the absence of fossil wood denotes the marine origin of the basal Wilcox, but the absence of pure limestone and of protozoan fossils identifies these beds rather as a shallow lagoonal, semi-marine deposit.

The argillaceous basal beds grade into overlying sandy beds without perceptible unconformity. This sandy member is well ex-

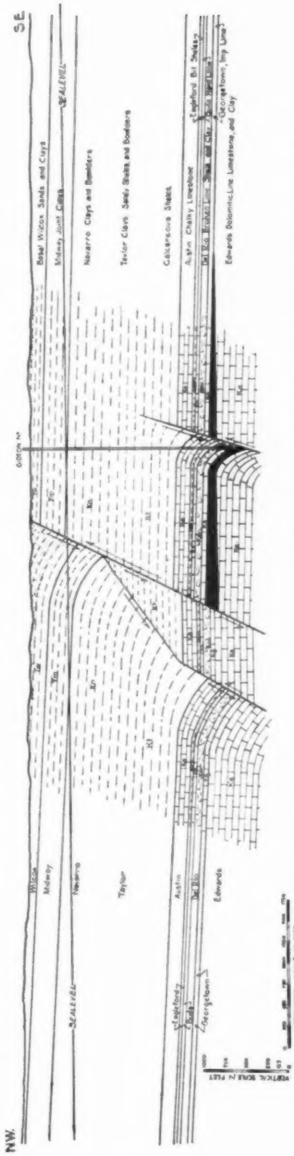


FIG. 5.—Northwest-southeast cross-section showing compound fault and inferred subsurface structure at Gideon No. 3

posed on the downthrown, northwestern side of the fault and at the southwestern and northeastern extremities of the uplift. It succeeds the basal beds on the basinward flank on the southeast side. These beds consist of laminated, micaceous sand and clay and massive cross-bedded sands which in general weather to light-sandy and reddish-brown sandy clay soils. Lignite and petrified logs, "cone-in-cone" concretions, and semi-quartzitic, pyritic, coarse-grained sandstone ledges are characteristic of the sandy phase of the Wilcox. The hard pyritic sandstone ledges are well exposed on the northwestern side of the fault and form a most reliable key bed. The attitude of the ledges near the fault is abnormal, the strata plunging strongly toward the southeast into the fault plane. This attitude is significant in studying the dynamic geology of the Luling structure. The typical perennial vegetation consists of blackjack and post oak; mesquite being relatively scarce. Fossils other than of petrified wood are apparently absent. The lithogic character and fossil content of this sandy phase of the Wilcox suggests a lacustrine, continental origin for these sediments.

STRUCTURE

The major structual feature that controls the accumulation of petroleum in the Luling field is a system of N. 35° E. trending faults having the downthrown side on the northwest. The structure may be designated as a faulted monocline. The dip of the fault plane at the outcrop on San Marcos River is 60° in a direction N. 35° W. Borehole data indicate that the dip of the fault plane is about 48° northwest in Guadalupe County and about 65° northwest in Caldwell County northeast of Seals Creek, with a consequent heave of about 1,800 feet and 1,000 feet, respectively, measured on the top of the Edwards pay lime. The displacement of the main fault varies from 450 to 500 feet. The highest points of the structure are at the extremities of the uplift, the middle portion being 40 feet lower (Plate X). The abutting of the basal argillaceous Wilcox on the southeast against the normally superjacent sandy beds on the northwest at the fault exposure indicates a major displacement or throw in the surface beds. The distance in the direction of the normal dip from the top of the basal argillaceous Wilcox and other markers at their normal stratigraphic position northwest of the fault to the corre-

sponding horizons on the southeast side is about 3 miles. Allowing a southeast dip of 100 feet per mile, the throw in the surface beds would be about 300 feet. However, the dip may be in excess of 100 feet per mile, and since the dip is greatly increased near the fault, the throw may be 400 feet or more. Well data prove that the throw of the major fault measured on the top of the Edwards is nearly 500 feet (Fig. 3). The large amount of cross-bedding in the sandy Wilcox renders accurate determinations of the normal dip impracticable but it is known that a normal southeast dip prevails from the northwest to within about 1,000 feet of the fault. At this point, the southeastward dip increases gradually to 25° southeast at the fault. Figures 4 and 5 illustrate the general attitude of the surface strata on both sides of the fault, the strata on the northwest dipping into the fault plane. At the outcrop on San Marcos River a very slight northwest drag is observable on the southeast side, but this drag does not seem to persist for a distance greater than 50 feet southeast of the fault. In general, the dip of the upthrown beds is normally southeast, and no strong reversals in dip are observable in the surface beds.

The closure to the Luling structure, as based on surface observations, is afforded on the northwest by the main fault and the accompanying downthrow on that side; on the southeast by the normal basinward depression occasioned by the regional southeast dip; on the northeast by the Joliet east-west cross-fault and consequent stratigraphic low position; and on the southeast by a marked stratigraphic depression. These determinations as to closure, made in the fall of 1922, illustrate the value of geology in the interpretation of fault structures.

SUBSURFACE GEOLOGY

Information as to the limits and general conditions of the structure obtained by the drill have confirmed conclusions based on surface geology, and in addition have afforded evidence of two unexpected structural conditions not positively reflected in the surface geology.

In the United North and South Oil Company's Gideon No. 3 an abnormal deformation was discovered (Fig. 5), the top of the Edwards oil horizon being encountered about 400 feet lower than

normal. Cores were taken from the Austin, Eagleford, and Edwards, and all of the samples showed an inclination, presumably toward the southeast, of about 45.° In spite of this seemingly unfavorable condition, the well has proved to be a very good producer, the oil being of standard Luling grade. The character of the pay in this well is identical with that of the Edwards pay at its normal level and the water coming with the oil is of the same quality as that of wells producing from normal levels. Although the vicinity of Gideon No. 3 has been fairly closely drilled, no further evidence of this unusual condition has been discovered. No vertical displacement is revealed by other wells in this locality; consequently, the condition cannot well be identified as a fault paralleling the main fault, although it has some of the characteristics of a major fault. The fact that the oil in the Gideon No. 3 producing formation has not been replaced by water suggests that the oil may have been present when the deformation occurred and that the porous beds may have been sealed at the point of deflection from the normal dip by compacting of the formations at that point.

On the northwestern side of the field in Caldwell County, between the Tiller and W. F. Mercer tracts, well data seem to indicate a compound fault. The producing horizon is cut by a minor fault instead of by the major fault and a narrow block with the top of the Edwards from 100 to 125 feet lower than the top of the productive Edwards on the southeast seems to lie between this minor fault and the main fault on the northwest (Plate 10 and Fig. 5). However, the surface geology does not suggest such a condition directly, and the well data available are not complete enough to delimit its extent accurately. The heave of the fault cutting the northwestern edge of production in the area does not seem to exceed 1,000 feet.

The geologic column in the Luling field comprises the formations ranging from the Wilcox downward to and including the Trinity or basement sands of the lower Cretaceous. A study of the accompanying geologic map and sections reveals the obvious fact that the geologic column of the wells northwest of the fault must of necessity differ materially from that of wells on the southeast. The following descriptions are based on the writer's examination and interpretation of well logs and available cuttings and cores.

The thickness of the basal argillaceous Wilcox is estimated to be

about 50 feet at the surface trace of the fault. The thickness of the sandy beds overlying the basal Wilcox on the northwest side of the fault is found to be at least 400 feet.

The Midway underlying the Wilcox is estimated to be about 280 feet thick. A study of the Tertiary section in the United North and South Tabor No. 16 was made by the writer to determine the thickness of the Midway and Wilcox (Fig. 6). Accordingly, the thickness of the Tertiary should be between 330 and 380 feet immediately southeast of the fault, and it is estimated to attain a maximum of about 800 feet on the northwest. The Tertiary beds are drilled with the fishtail bit on the southeast side of the fault and with both the fishtail and the roller bits on the northwest side.

Underlying the base of the Tertiary are found the Navarro-Taylor beds of the Upper Cretaceous. The Navarro and Taylor contact cannot be detected satisfactorily on the basis of lithology and reliable paleontology. The combined thickness of these beds is about 1,350 feet. The beds are of clay and sandy shales and bowlders and are readily penetrated with the fishtail bit.

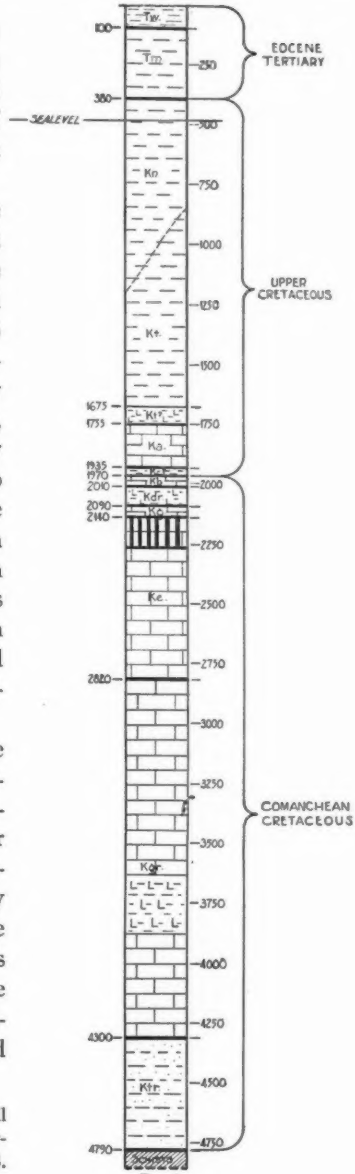


Fig. 6

Fig. 6.—Composite log of U.N. & S. Oil Co. Tabor No. 16 and Tabor No. 8. Surface—2140, Tabor 16; 2140–4875, Tabor 8.

The Austin chalk is the next underlying formation. The top of the Austin is taken by the writer to be the top of the hard limestone underlying the Taylor shales. However, this limestone, though hard, has an earthy, non-crystalline texture. The typical fossil form of the top of the Austin limestone is *Gryphaea aucella*. *Inoceramus crispii?* is another abundant form. A peculiar characteristic of the top and the base of the Austin is the presence of glauconite and an oil stain. This formation, logged by drillers as chalk rock, is drilled with roller bits. Pyrite occurs commonly in this formation. The thickness of the Austin "chalk rock" is 180 feet. The top of the formation is the most useful horizon-marker above the Edwards lime, and is the best guide in controlling the drilling along the faulted edges of the field.

The succession from the basal Austin chalk into the Eagleford formation is marked by a complete change in the character of the rocks. The glauconitic lime of the basal Austin overlies a body of dark, slightly sandy, thinly and evenly laminated, bituminous shales of varying hardness in which pyrite is common. The Eagleford shows considerable gas in the high points of the structure and very small quantities of oil of about 35° Baumé gravity are found in this formation. The thickness is about 35 feet. Both the fishtail and roller bit penetrate this formation satisfactorily.

The Buda lime, about 40 feet thick, occurs underneath the Eagleford. It is a relatively pure, non-pyritic, hard, dense, somewhat flinty lime, showing some glauconite at the top. This formation is drilled with the roller bit as it is too resistant for the fishtail. No readily identified fossils have been observed by the writer.

The contact between the Buda and the underlying Del Rio beds cannot be detected satisfactorily with the drill. There seems to be a gradual transition from the hard lime of the Buda into the "broken lime and shale" of the Del Rio. The thickness of the Del Rio is estimated to be about 80 feet. Both the fishtail and the roller bit penetrate these beds, although the latter operates more satisfactorily. Thin limestone ledges occur commonly. The clay and shale of this formation are unevenly laminated and are of a greenish-blue color. Pyrite nodules and pyritized fossils are found. The best guide fossil is a dwarfed form of *Exogyra arietina*.

Underlying the Del Rio is the Georgetown formation, which has a thickness of about 50 feet. The transition from the "broken lime and shale" of the Del Rio to the harder, dense, impure limestone of the Georgetown is very readily perceptible when drilling with the fishtail but rather indefinite with the roller bit. Although some fossils are found in the Georgetown, the formation can be identified more readily by its lithology and drilling character than its fossil content. Pyrite is scarce. The Georgetown is an impervious limestone and overlies the oil horizon in the top of the Edwards lime.

In the productive portion of the field, the top of the Edwards is encountered between the depths of about 1,590 feet and 1,720 feet below sea-level. On the Tabor and McKean lands at the extremities of the field the highest elevation of the Edwards is about 40 feet higher than in the middle of the field (Plate 10). The southeast dip of the top of the Edwards oil horizon varies from about 200 to 275 feet per mile. The upper Edwards consists in part of dolomitic limestone and shows a porosity of 5–30 per cent or more. The degree of porosity is variable and does not seem to be controlled by the stratification of the beds. In some wells, the top of the pay is extremely porous, but in most cases the wells encounter the highly porous formation at 15–30 feet below the top of the pay. In the major portion of the oil-saturated lime, the degree of porosity is uniform and regular. The exceptions consist of irregularly distributed, dense, hard, pyritic, chert-bearing limestone lenses of about 1 foot thickness which are underlaid usually by several feet of very porous, prolific, dolomitic lime pay.

The initial production of similarly situated wells is extremely variable. The degree of porosity of the pay rather than the degree of pressure seems to be the controlling factor. The pressure is regarded as uniform, but a differential porosity affords a variable rate of relief for the pressure, and hence an irregularity in rates of initial production from wells situated similarly with regard to structure. Fossil *Rudistidae*, *Pectinidae*, and *Miliolidae* are fairly well represented in the oil horizon. The thickness of the pay varies from 50 to about 150 feet. The porous character of the Edwards persists below the oil horizon. At about 250 feet below the top of the Edwards the formation is very cavernous, and difficult to drill

through because of losing returns of the drilling fluid. The total thickness of the Edwards formation appears to be about 730 feet.

No attempt was made by the writer to differentiate the Edwards and the Comanche Peak limestone which normally underlies it. If a clay member comparable to the typical Walnut Clay at the outcrop occurs its identity cannot be established upon lithological or upon available paleontological evidences as revealed by well samples.

The Glenrose formation underlies the Edwards and appears to be about 1,450 feet thick in the Luling field. This formation consists of "broken" dolomitic lime, limestone, and dark shales with little or no pyrite. Fossils are fairly abundant and some large Foraminifera resembling *Orbitolina texana* have been observed in the upper part. The typical lime phase of the Glenrose is succeeded by a series of white calcareous sands, laminated greenish sandy shales and clays, and red sands and conglomerates with a thickness of about 500 feet. The basal beds are of coarse gravels and conglomerates, which appear to be nonfossiliferous, and are provisionally classified as the Trinity or basement sands of the basal Comanchean. At a depth of about 4,600 feet in the United North and South Oil Company's Kelley No. 1 a stratum of oil-stained sand was encountered.

In the Tabor No. 8, Kelley No. 1, and Tiller No. 2 wells of the United North and South Oil Company, the 500 feet of the foregoing Trinity sand phase was found to be underlaid by varicolored schists of a talcose texture. However, a chemical analysis of the talcose schist does not agree with the talc determination. The analysis shows no carbonate and appears to be an aluminum silicate with other metal silicates and oxides in combination. The iron, probably in the form of oxide, lends color to the schist. The analysis of a ferruginous schist sample is given on page 647.

R. D. Fash, of the Fort Worth Laboratories, analyzed this schist and agrees that the "loss on ignition" may represent water of crystallization. A peculiar phenomenon observed in drilling these schists consisted in the heating of the drilling mud which had to be cooled repeatedly with cold water. This fact suggests the probability that an abnormally high temperature obtains in the metamorphic complex underlying the sedimentaries in the Luling field, and gives

credence to the theory that an igneous ridge may underlie the structure. There is some doubt as to the age of the schists, but it is convenient to designate them pre-Cambrian. However, they may well be of early Mesozoic or of Paleozoic age, and may represent post-Cambrian shales metamorphosed by diastrophism incident to

ANALYSIS OF SCHIST FROM WELLS IN THE LULING FIELD

	Per Cent
Silica	55.13
Aluminum oxide	27.31
Iron oxide	5.33
Calcium oxide	0.00
Magnesium oxide	1.46
Potassium oxide	3.46
Sodium oxide	1.07
Moisture	0.30
Loss on ignition	6.37

igneous intrusions. The fact that igneous intrusions such as Pilot Knob in Travis County, Texas, are probably of Cretaceous age renders it probable that several stages of igneous activity may have occurred in the time interval between the pre-Cambrian and the early Cretaceous. The writer indorses the theory that this metamorphism was caused by igneous disturbances of a regional character.

DYNAMIC GEOLOGY

It is generally conceded that one of the main forces that caused the Balcones fault lay in the weighting-down of the Upper Cretaceous and Tertiary sediments on the seaward side, operating against the uplifting tendency of the Central Mineral Region igneous masses. The action of such forces would logically result in faulting with downthrow on the southeast, such as the main Balcones. However, in the case of the Luling fault and similar structures such as the Mexia-Powell and related faults, the downthrown side is on the northwest—the reverse of what one would expect on the grounds of the theory applicable to the main Balcones fault. Moreover, faulting of the Balcones type with the fault plane dipping southeastward would result logically in a shortening or compression of the basinward beds

causing anticlinal structures oriented along the strike of the strata. But the Luling type structures are not true anticlines because there are no extensive reversals in the strata on the northwest. Inasmuch as metamorphic rocks of intrusive aspect were found underlying the Luling sedimentaries, it is strongly suggested that the major uplifting force was supplied locally by a deep-seated intrusion and that the strong southeast dip into the fault plane was caused by the compression on the basinward strata resulting from the Balcones fault action (Figs. 4 and 5). The Gideon No. 3 condition (Fig. 5) also illustrates the theory that a strong compressional force along the direction of the regional dip was exerted on the strata in conjunction probably with the major uplifting forces.

The origin of oil in the Luling field may be explained in part by several theories. The oil may be indigenous to the Edwards lime and the porosity induced by shrinkage upon dolomitization may have afforded passage for the lateral and upward migration of the hydrocarbons into the high parts of the Edwards. Moreover, the process of dolomitization may have freed the hydrocarbons from the organic remains in the Edwards and Glenrose limestones, and rendered their accumulation possible. In the Edwards Plateau, traces of asphaltum are reported from portions of the Edwards and Glenrose formations. The theory that the oil was generated or distilled from Trinity or pre-Cretaceous formations by heat from suspected igneous intrusions and that it migrated up the fault plane for lodgment in the Edwards finds considerable favor. The fact that gas, oil, and water of the regular Edwards pay quality migrates up the fault plane even higher than the Edwards is demonstrated in the cases of several wells on the J. E. Allen "A" lease, in Guadalupe County, on the northwestern side of the field. Again, on the northwest side of the fault, connate and ground waters migrating basinward through the Eagleford shales and other bituminous strata may have carried oil, and upon encountering the fault plane may have migrated upward and lodged in the porous upper Edwards. On the southeastern side of the fault, the hydrocarbons and waters in the Eagleford shales may have been affected by the process of gravitational separation forcing gas and oil to the higher points at the fault and thence down the fault plane into the porous beds in the Edwards.

The gradual accumulation of connate and ground water in the basinward portion of the shales could reasonably have forced considerable quantities of oil into the Edwards via the fault plane. But the oil indigenous to the Eagleford is of about 35° Baumé gravity, whereas that of the Edwards is of about 27° Baumé gravity. It is possible that each of the above-mentioned theories explain in part the origin of the oil.

The occurrence of water is customarily regarded as a damaging factor. However, the important rôle of water in the dynamics of oil migration must not be overlooked. It would seem that the presence of abundant bottom or edge water, as is the case in the Luling field, is beneficial in that it gradually replaces the oil completely from the bottom and the edges of the reservoir and thus makes for a greater ultimate oil recovery than would be possible without it. The occurrence of water in the Luling field is exceedingly irregular. In some wells water has invaded the highly porous portions of the upper part of the oil horizon, rendering it very difficult to control water encroachment. In several cases the upper pay had to be abandoned and the lower pay exploited for production. The water appears as early in wells high on the structure as in those on the southeast limit of gusher production. In fact, the wells making the most water are those that come in with the largest flush production regardless of position of the structure. The porosity of the pay is variable both as to degree and areal extent, and seems to be the controlling factor in the volume of daily production from the individual well. Inasmuch as the oil flows more readily from the highly porous portions of the pay, wells penetrating such highly porous pays withdraw the flush oil rapidly and bottom or edge water follows in the wake of the oil. Since the porosity does not seem to be controlled absolutely by the stratification of the lime the more porous channels, after being partially depleted of oil, form ready avenues for the entrance of water from the normal edge or bottom water levels with which these porous channels may connect. The origin and source of the water should be connected with the origin and migration of the oil, and the theories that are cited for the origin of the oil should explain in a large measure the origin of the water.

CHARACTER OF GAS, OIL, AND WATER

Considerable gas is produced with the oil from wells high on the structure. This gas is of a good fuel quality but contains large quantities of hydrogen sulphide as an impurity. Before the gas can be used profitably in internal combustion engines, it has to be passed through water to separate the hydrogen sulphide from it.

The oil has an asphalt base and shows no paraffin. The temperature on an average is about 100° F. The gravity varies from about 26° Baumé in Guadalupe County to from 27° Baumé to 29° Baumé in Caldwell County, the higher gravity oil being found at the northeast end of the field. In general, the gravity of the oil appears to have remained fairly constant. The oil yields about 8 per cent naphtha, 32 per cent gas oil, and 50 per cent light lubricating oil by the ordinary topping process, and there is no free gasoline or kerosene present. Upon high-pressure distillation, the oil yields about 55 per cent gasoline, 7 per cent gas oil, and a low grade of fuel-oil residue.

The water has a chlorine content of 5,000–6,000 parts per million. It is slightly saline and has a bitter taste due to the presence of calcium chloride. It is highly charged with calcium bicarbonate and is saturated with hydrogen sulphide. The temperature of the emulsion is higher than that of the water-free oil. As long as a well flows pipe-line oil the temperature is about 100° F., but after the entrance of water the temperature rises slightly above 100° F. There seems to be no appreciable difference between the chlorine content of waters taken from different parts of the field. In the writer's opinion, all the waters found in the Edwards oil horizon have a common source, hence the practical uniformity in quality.

DEVELOPMENT PROBLEMS

The policy of some Luling operators has been to drill all possible locations. This has resulted in very close drilling in many parts of the field. In those parts of the field, however, where the wells have been widely spaced the rate of decline has been much more gradual and the capital investment per well has brought larger returns by about 30 per cent. It costs about $15,000 to drill a well in the Luling field, therefore, the drilling of some four hundred

wells has cost about $6,000,000. The total production of the field at the close of the year 1924 was about 14,500,000 barrels. It is readily apparent that an agreement among the operators to have spaced all wells along property lines 600 feet instead of 300 feet apart would have enhanced greatly the realization of larger profits, insured a longer life for the field, and economized operations in general.

Because of the proximity of San Marcos River, drilling operations were never hampered seriously by the lack of water. Water lines from the river supply all parts of the field.

The drilling is done exclusively by the rotary method. The large thickness of clays and shales of a caving nature above the Austin chalk render the use of cable tools impracticable and unprofitable. Ordinarily, a well can be completed in from ten to thirty days' total time. However, on the northwest side of the surface fault, more time is required than on the southwest side because of the occurrence of thick beds of very hard, pyrite sandstone at a shallow depth. As many as four or more sets of roller bit cutters and cones have been used in some wells to penetrate these sandstones.

On the higher portions of the structure, it has seldom been found necessary to swab a well in order to bring it in. Usually a few hours' bailing has served to induce the well to flow. In general, the wells have been allowed to flow through the casing until production declined to about one hundred barrels, then the tubing was run and the production increased by flowing through the tubing. Finally, the wells are put on the pump, the customary method of pumping being by jacks. During the latter part of 1924 many wells were standardized and put on the beam. Shooting with nitroglycerin has been tried with fair success in cases of wells of low initial production from a pay of low porosity. In wells where water had intruded to the extent of lowering production very considerably, attempts at water shut-offs were made by plugging back with lead wool. On the whole, this plugging back has been successful in decreasing materially the percentage of water and increasing the production of oil. In several cases, the water shut-off was complete and the oil restored to a pipe-line grade.

Two methods of treating the emulsion find favor with the opera-

tors in the Luling field: one is by use of Tretolite and the other by electrical dehydration. About 80 per cent of the oil is dehydrated by the electrical process.

PRODUCTION

Figure 7 shows the monthly production and cumulative production curves and a curve based on number of wells producing each

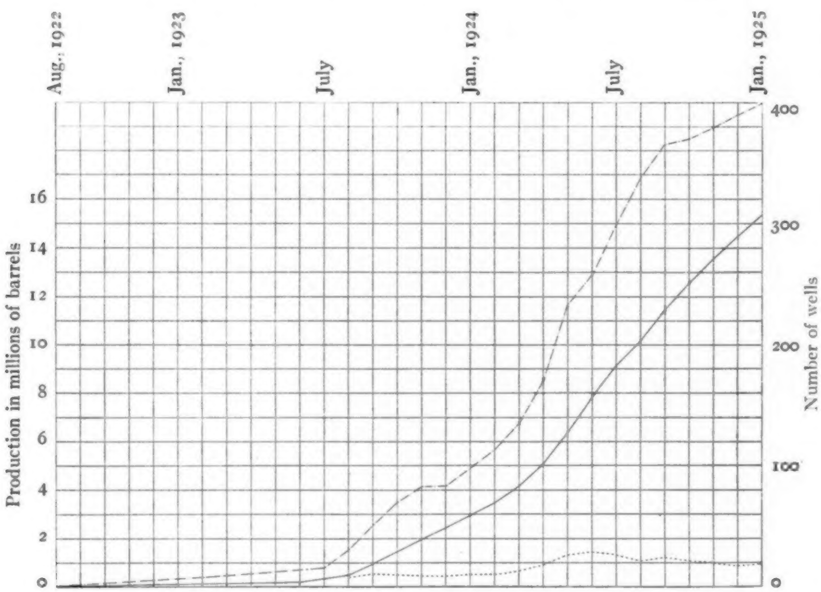


FIG. 7.—Well and production curves of the Luling field

Cumulative number of wells
Cumulative production
Monthly production

month. The curves illustrate the tendencies of oil production over a period from August 14, 1922, to and including January 31, 1925. The initial daily production of wells in the Luling field averages about 900 barrels; the extremes being as low as 50 and as high as 11,500 barrels.

The proved acreage in the field approximates 2,100 acres. The

total production of the field was about 15,350,000 barrels on January 31, 1925. The yield per acre, therefore, was about 7,500 barrels up to that time. Judging from the trend of the production curves one would be led to anticipate an extended period of well-sustained production.

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DISCUSSION

F. H. Lahee: I think that both Mr. Brucks and the United North and South Oil Company are to be congratulated: Mr. Brucks for the excellence of his presentation, and the company for their willing co-operation in permitting the publication of their data.

I want to ask Mr. Brucks several questions.

In the first place, was Mr. Brucks able, through his study of all the data, to arrive at any conclusion regarding the possible source of the oil? Has it come up the fault on the west, or has it migrated up the bedding planes from the east? I think that his section *CC*—the lowermost of the three on one of his plates—indicated that the oil came from the east; for the pool was shown to be limited on the west by the minor fault, while, if the oil had come up the faults, perhaps we should have expected the bigger accumulation against the major fault, farther west. Possibly this is due to a difference in porosity of the lime adjacent to the two faults.

Mr. Brucks: I have arrived at no satisfactory conclusion as to the source of the oil. If the oil is indigenous to the Edwards lime, it is more likely that it

migrated up the bedding planes from the southeast than that it migrated up the fault plane. There is no appreciable difference in the porosity of the Edwards lime on the southeast, compared with that of the northwest side of the fault. The fault block in question appears to be nearly horizontal, and since the top of the Edwards in this block is lower by about 125 feet than that on the productive side of the fault, the oil should have sought the higher parts of the Edwards on the southeast. The thickness of the Edwards pay at that point is less than 100 feet.

MR. LAHEE: A very important feature brought out by Mr. Brucks, important for practical as well as theoretical reasons, is the dip of the strata southeastward into the fault on the western or downthrown block. This is exactly the opposite of the expected condition. If this were interpreted as drag by field geologists, they would certainly infer that the east block was dropped down in respect to the west. Has Mr. Brucks any explanation of this feature?

MR. BRUCKS: The strong accentuation of the southeastward dip on the downthrown side of the fault may be due to the forces of tangential compression exerted on the strata on the basinward side of the main Balcones fault at the time the main Balcones faulting occurred. The uplift in the Luling field may have been caused by a suspected local deep-seated intrusive or positive ridge underlying the schists.

MR. LAHEE: My third question is this: Does Mr. Brucks regard the fault shown bounding the pool on the west as a single fault, or as a group of intersecting faults? I should like to know also whether he found any evidence of an increase of the major displacement with depth. In reference to the water situation, is there a notable difference between the level and composition of water in the pay bed on the east side of the field as compared with that on the west side?

MR. BRUCKS: I believe that the faults closing the Luling structure belong to a single system of connecting faults, with several changes of direction, and that they are not intersecting faults. I have no evidence at hand that proves conclusively that the major displacement increases with depth, but I suspect such a condition. Not having made thorough analyses of all the well waters in the area in and around the Luling field, I cannot answer the last question with assurance. However, there should be no difference because the Edwards is equally porous on both sides of the fault, and there should be ready an uninterrupted communication between the water-filled Edwards on the two sides of the fault.

THE SOUTH DAYTON SALT DOME, LIBERTY COUNTY, TEXAS[1]

W. F. BOWMAN
Houston, Texas

ABSTRACT

The South Dayton-Liberty salt dome is a characteristic Gulf Coast salt dome. The salt core is 1½ by 2½ miles in diameter and comes to within 500 feet of the surface. The major diameter strikes N. 30° E. The cap is 150-250 feet thick and consists of gypsum and anhydrite with a thin capping of limestone. The beds penetrated in drilling are Jackson to Recent in age. The top of the dome has been well tested; although shows of oil and sulphur were had, neither was found in commercial quantity. The lateral sands have be en tested only by three moderately deep wells and still offer possibilities of discovery of production.

INTRODUCTION

Most of the data for this paper was collected during 1922 by the writer and other members of the geological department of the Rio Bravo Oil Company under the direction of Dr. E. T. Dumble and Mr. John R. Suman, and is published with their permission. The history of development was compiled largely from periodicals published at the time of the early exploration around the dome. Early reports of the Rio Bravo Oil Company contained much information. The companies which drilled the different wells have been very liberal with such of their well logs as were preserved. Logs of many of the early wells were never kept. Early operators have given some records from memory.

LOCATION

The South Dayton salt dome is in the south central portion of Liberty County, Texas, about 38 miles northeast of Houston. It is in the Trinity River bottoms about 2-5 miles south of the Texas and New Orleans Railroad (Southern Pacific lines). Liberty, on the east side of Trinity River, and Dayton, on the West, both on the Texas and New Orleans Railroad, are the nearest towns. The river flows across the center of the dome, and accordingly the northeast

[1] Known equally well as the South Liberty or the South Liberty-Dayton salt dome.

half is most accessible from Liberty and the southwest half from Dayton. Most of the area is subject to overflow, and from two to five months each year it is practically impossible to get to the area at all.

Other domes in the region are Hull, 12 miles; Batson, 18 miles; Saratoga, 22 miles; and Sour Lake, 25 miles—all in a northeastward direction. Davis Hill is 18 miles north; North Dayton, 12 miles northwest; Humble, 25 miles west; and Barbers Hill, 12 miles southwest. All of these domes have been found productive except Davis Hill and South Dayton. All of the productive domes have yielded large quantities of oil with the exception of North Dayton and Barbers Hill.

HISTORY

The finding of oil on Spindletop salt dome in 1901 started a search for salt domes throughout the Gulf Coast country. South Dayton almost immediately attracted attention. The indications in this area were sulphur springs, gas escapes, and oil seepages. The most important of these was a spring located near the south end of Duncan Lake in the southwest portion of the Matthew G. White survey. It is said that bubbles of gas as large as one's fist could be seen coming up through the deep-blue sulphur water. Oil showings occurred also on the water. Similar indications were observed to the southwest across the river.

Because of these favorable signs, a company organized by Messrs. Bullard and Wilson during the year 1902 drilled three wells in the Bullard and Wilson subdivision on the west side of the river. Good showings were encountered in each test. Well No. 3, which was completed later by the Liberty-Marble Falls Oil Company in 1905 at a depth of 419 feet, was thought for a while to be a gusher from a depth of 400 feet. A rush was made to the area, and the prices of acreage soared to high figures, but sulphur water and salt water soon drowned out the oil and dampened the ardor of the promoters.

In 1904 the Sulphur Springs Oil Company was organized by Mr. E. B. Pickett, Sr., and Judge C. F. Stevens, and this company started two wells. The first was drilled near the sulphur spring in the southwest corner of the Matthew G. White survey. In order to keep other leases from expiring, the hole was abandoned at 400 feet and the rig skidded a few hundred feet south where a second well was started. These locations were made here because of the gas and oil showings in the sulphur spring.

In 1905 the Liberty-Marble Falls Oil Company was organized and took over both the Bullard-Wilson and the Sulphur Springs Oil Company holdings. No. 2 of the Sulphur Springs Oil Company, east of the river, was completed to a depth of 821 feet. This well encountered gypsum at about 500 feet and is reported to have gone through a very good showing of sulphur at around 600 feet.

Encouraged by the results of these first five wells, a number of companies were organized and numerous wells were drilled. Practically all of the wells

encountered good showings of oil, but these were soon drowned out by salt and sulphur water. By the end of 1906, in addition to the Liberty-Marble Falls Oil Company, the Heywood Oil Company, the Pickett-Henry Company, and the Paraffin Oil Company had started operations in the field. Seven wells had been completed on the east side of the river and ten on the west. With the exception of the Liberty-Marble Falls No. 1 Bullard-Wilson subdivision and the Heywood Oil Company well east of the river, which were 1,200 and 1,500 feet deep, respectively, none of the wells were over 900 feet deep.

In 1907 two more wells were drilled, one on the east side of the river for sulphur and one on the west side for oil. On account of the very favorable reports of solid sulphur encountered in the Liberty-Marble Falls Oil Company well which had been taken over from the Sulphur Springs Oil Company, the American Sulphur Company of St. Louis, headed by Dr. A. L. Lyons, started the drilling of five wells. The first was located several hundred feet northeast of the Liberty-Marble Falls Oil Company well. In this well considerable sulphur was encountered, but it is said was disseminated in small pieces throughout gravel. The second well was drilled only a short distance from the old Liberty-Marble Falls well, and practically the same conditions were found. Their Nos. 3, 4, and 5 wells did not encounter either oil or sulphur in commercial quantities.

By the end of 1916 a large number of shallow wells had been drilled in search for cap-rock oil. This was a heavy oil and seemed to be in a thin scum or layer over the salt water. Numerous wells set casing above it and then drilled in, but in each case the salt water broke through the oil. Several of these wells are still flowing salt and sulphur water.

In 1917, after deep oil had been found on the salt domes in other portions of the Gulf Coast area, the Empire Gas and Fuel Company started a series of tests for deep oil around the dome and drilled, in all, fourteen wells. Of these, four encountered cap rock and salt and were abandoned at shallow depths. Their first deep test was drilled on the J. Reviere land in the M. G. White League. This well encountered an oil sand at 2,876 feet which was about 20 feet thick. Strainer was set and the well blew out and threw oil over the derrick, but the strainer sanded up and the production was never brought back. The oil was about 28° Baumé gravity. Because of this show, the company bought 10 acres of the Beard tract about 1 mile to the east, at a price of $12,500. A well 3,485 feet deep was drilled on this tract, but no encouraging results were obtained. During this time the Empire Gas and Fuel Company had started drilling on the west side of the river. Two wells were drilled on the Charles Wilson land to a depth of about 3,000 and 3,600 feet, respectively. Three were drilled on the Jackson land to depths of less than 1,500 feet. One of these wells pumped oil for several weeks, but was not commercially profitable at the prices then prevailing. Three deep wells were drilled on the Welder land, but though each had showings, nothing of importance was encountered. In 1920 the Empire Gas and Fuel Company withdrew from the field without having developed any production. Their operations together with the drilling of other companies have pretty well outlined the dome.

In 1923 the Union Sulphur Company began a series of tests on top of the dome in search for sulphur. To the present time they have completed six and are drilling two others, but the results of these tests have not been made public. A deep test for oil is being made on the northeast side of the dome by the South Liberty Oil Company. This test is only about 50 feet south of the J. Reviere well drilled by the Empire Gas and Fuel Company and has encountered about the same oil showings as were obtained in that well.

Drilling which has not been referred to heretofore and which helps to outline the dome was that of Grandberry and Staiti on Block 10 of their own subdivision and that of Hamilton *et al.* on the Condit land in the southwest corner of the David Minchey survey. The Grandberry and Staiti well went about 1,750 feet without encountering dome material. The drill stem was twisted off and the hole lost without any tests having been made. Little or nothing has been learned about the Condit well except the reported depth, 2,670 feet. It is said that no dome material was encountered.

To the present about fifty-six wells have been drilled in the field. Thirteen of these were drilled off the area of the salt; the others were shallow cap-rock tests.

TOPOGRAPHY

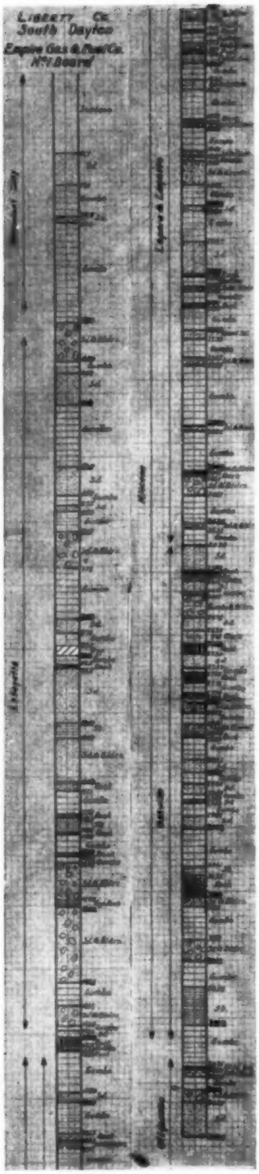
Trinity River flows across the center of the dome from north to south. Most of the dome lies in the bottom lands of the river, and the topography is mainly typical of the Trinity bottoms (Fig. 1). A low ridge encircles the north, northeast, and east sides of the dome. The highest elevation along this ridge is on the northeast edge of the dome where it reaches 34 feet. The average bottom lands range between 10 and 18 feet above sea. This ridge is probably due, in part, to doming.

The bottom lands in the vicinity of the dome are about 4 miles wide. The bank on the west side opposite the dome is some 50 feet high and forms an east-facing scarp. On the east side the bank is not so regular but is well defined. The banks are typical of the natural levees along east Texas rivers.

STRATIGRAPHY

The South Dayton salt dome lies within the area of the Beaumont clays, about 8 miles south of the contact of these clays with the underlying Lafayette. The material exposed at the surface over most of the dome is silty and loamy alluvium from Trinity River. Along the ridge on the northeast edge of the dome and near the Reviere

FIG. 1.—Topographic map of the South Dayton salt dome



wells there are some fine, loose, orange-colored sands which are believed to belong in the Beaumont clays, but may possibly belong to uplifted Lafayette. In the wells on top of the dome, sands and gravel are encountered down to the cap rock. For this reason, the formations directly over the dome have been assigned to the Lafayette with the Beaumont clays lapping upon the east side.

In the wells which have been drilled on the flanks of the dome the respective contacts between the different formations are not distinct, but they have been placed as shown in the cross-sections. In the Empire Gas and Fuel Company's Beard well (Fig. 2), which is believed to be far enough off the dome so that the formations are little disturbed, the Beaumont clays are about 400 feet, the Lafayette about 1,100 feet, and the Miocene about 1,900 feet thick. These classifications have been made entirely on the well log as reported by the driller.

There is a striking similarity between this section and that which is exposed at the surface along Brazos River from Hidalgo Bluff in Washington County southward to below Hempstead. Mr. William Kennedy has divided the Brazos River section into the Lagarto, Lapara, and Oakville, which are the South Texas subdivisions of the Miocene. Because of this similarity these terms have been inserted on the cross-sections although these subdivisions are usually grouped as the Fleming clay east of Brazos River.

FIG. 2.—Cross-section of well of Empire Gas and Fuel Co. No. 1 Beard.

In the Beard well the Beaumont clays are inferred to include the clays and fine sands that are encountered at the surface down to 390 feet. In the Lafayette is included the material encountered between 390 and 1,500 feet, composed mostly of sand and gravel and a little clay. Gravel is believed to be characteristic of the Lafayette. Between 1,500 and 2,560 feet there is a marked reduction in the proportion of the sand and gravel to the shales, gumbos, and clays. The gumbos and shales compose about two-thirds to three-fourths of this section, whereas in the overlying Lafayette the sands compose about two-thirds to three-fourths the section. The section from 1,500 to 2,560 feet is believed to correspond to Kennedy's Lagarto-Lapara exposed in the vicinity south of Chapel Hill in Washington County and along Brazos River from the H.&T.C. Railroad bridge south to a point below the wagon bridge on the Hempstead-Bellville road. In the section from 2,560 to 3,212 feet there is again an increase in the amount of sands and gravel in the section. The driller reports oyster and other sea shells. This portion of the log is believed to correspond to the Oakville as it is exposed in Hidalgo Bluff and north of Brenham in Washington County. Between 3,212 and 3,375 feet are shales which may be either Oakville (Fleming) or Oligocene since there is shale in both the base of the Oakville and the top of the Oligocene. Below 3,375 feet sands again increase in amount. The break at 3,375 feet corresponds with a change in the J. Reviere well at 2,900 feet which the paleontologists report to be the top of the Oligocene.

The only well around this dome from which samples have been obtained for microscopic examination is that of the South Liberty Oil Company. This well, which is located about 50 feet south of the Empire's J. Reviere well, is now less than 3,300 feet deep. Paleontologists who have examined the samples are agreed that the material between 1,150 and 2,900 feet is typical Miocene. Miss Ellisor, of the Humble Oil and Refining Company, who has examined samples from 2,986, 3,001, and 3,146 feet, reports re-worked or worn Oligocene and Cretaceous Foraminifera at 2,986 and 3,001 feet, and typical Middle Oligocene Foraminifera at 3,146, suggesting transition beds at 2,986 and 3,001 feet. Miss Lane, of Mr. Alexander Duessen's office, and Miss Ellisor, who have examined samples between 3,237 and 3,257 feet, report material of Jackson age.

STRUCTURE

The subsurface geology can best be understood by reference to the accompanying maps and cross-sections. The dome has been outlined as shown. It is elliptical in shape with its axis extending

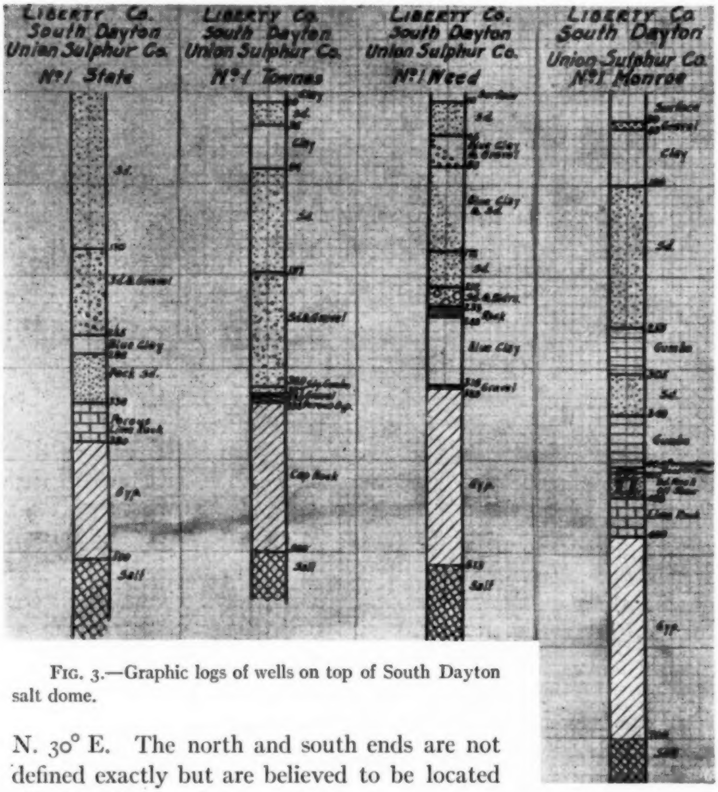


FIG. 3.—Graphic logs of wells on top of South Dayton salt dome.

N. 30° E. The north and south ends are not defined exactly but are believed to be located about as shown.

The salt core is nearly flat on top; it is highest at center and dips gently toward the edges; the east slope is steeper than the west. The sides of the salt core are very steep, but there are no wells yet drilled which indicate the exact slope at any place. The wells drilled either have encountered the cap rock and salt at shallow depths or

have failed to encounter dome material at all. There is a possible exception to this in the Empire No. 4 Welder which may have encountered dome material at a depth of 2,062 feet.

Across the north end of the dome the cap is encountered at depths between 320 and 440 feet, and it ranges from 170 to 262 feet in thickness. Near the center of the dome the cap is composed entirely of gypsum while toward the edges limestone with a thickness of as much as 40 feet comes in on top the gypsum. The gypsum is thickest near the eastern edge of the cap-rock area. The cross-section A–A (Fig. 4) is drawn to scale, and the data composing it are believed to be accurate. The conditions across the south end of the dome are shown in cross-section B–B (Fig. 5). In this section the cap rock is much thinner than farther north.

If the normal dip and thicknesses of the outcropping beds be considered, the Lafayette would be expected at about 480 feet beneath the surface at

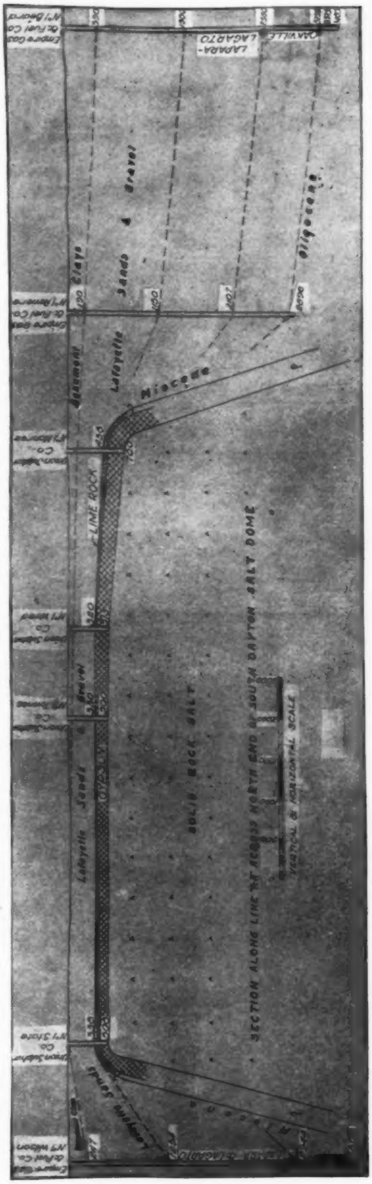


FIG. 4.—Section across north end of salt core

South Dayton, the Miocene at about 1,850, and the Oligocene at about 3,300 feet. According to our lithologic determination of the formations in the Empire Gas and Fuel Company's Beard well, which is far enough from the dome not to have been affected by any great uplift, the Lafayette was encountered at 390 feet, the Miocene at 1,500 feet, and the Oligocene at 3,375 feet. As compared with the Beard well, the Reviere wells show an uplift of at least 500 feet on the top of the Oligocene, 350 feet on the Miocene, and about 200 feet on the top of the Lafayette. The highest recognized Oligocene in the Riviere well is Middle Oligocene. If Upper Oligocene is present in the Beard well, then the Oligocene uplifted must exceed 500 feet. The lesser uplift shown by the upper

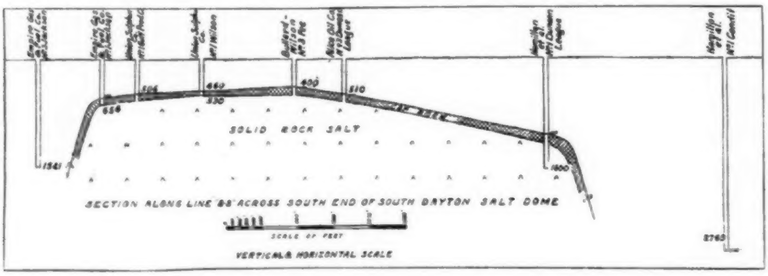


FIG. 5.—Northwest-southeast section across the south end of the dome

formations is probably due to the thinning of the formations near the dome and to the bottom of the well being closer to the dome than the top.

ORIGIN AND AGE OF THE DOME

The origin of the dome may be associated with lines of weakness, which developed from the same forces that caused the Balcones and Mexia-Powell lines. The direction of the major axis of the dome, which is N. 30° E., seems to be the general direction of the major axis of several of the domes, Stratton Ridge, Saratoga, and others, and is approximately parallel with the Mexia-Powell line of faulting. Stratton Ridge, Goose Creek, Barbers Hill, South Dayton, and Batson can be placed on a line with the same general strike.

The age of the dome is perhaps the same as that of the Balcones

and Mexia–Powell lines of faulting, that is, Eocene or later. Around the dome the Oligocene, Miocene, and Pliocene have been uplifted. There seems to have been a period of erosion at the beginning of Lafayette times which removed from above the dome the formations which were laid down prior to the Lafayette. After the Lafayette was laid down, the movement continued and elevated the Lafayette some 400 or 500 feet above its normal position.

FUTURE PRODUCTION

This dome has been fairly thoroughly tested for oil in sands above the dome and in the cap rock. Good showings have been reported from both, but it is not likely that commercial oil will ever be developed in either.

For deep oil the dome has been tested only in three localities. The Empire Gas and Fuel Company and the South Liberty Oil Company wells on the J. Reviere land off the northeast edge of the salt dome were each good tests. The Empire Gas and Fuel Company well went to 2,896 feet. A show of light oil in a sand near the bottom threw oil over the top of the derrick, but there was apparently no great quantity of oil. The South Liberty Oil Company well, which is near the Empire well, encountered showings at about the same depth. This test, which is well located with respect to the dome, is now drilling at 3,260 feet in beds of Jackson age showing oil.

The Empire Gas and Fuel Company Wilson wells on the northwest side and the same company Welder wells on the southwest edge of the dome were probably fair tests of the Miocene and possibly of the Upper Oligocene. Good showings were reported in each of these formations, but production was not developed. In the Empire Gas and Fuel Company's Jackson wells near the center of the west side a small producer was obtained, but the wells were less than 1,550 feet deep. With the foregoing exceptions the potential possibilities of the lateral sands are untested.

NOTE

Since writing the foregoing paper, the South Dayton dome has become productive of oil. The producing area is located off the northeast flank of the dome and is known as the South Liberty field. The discovery well, known as the Winfree Trustee well on the E. W. Pickett land, is located a little more than

500 feet southeast of the South Liberty Oil Company well on the J. Reviere land, which was drilling at the time of the writing of the foregoing paper.

The discovery well came in December 31, 1924, for an initial production of 500 barrels pipe-line oil. The oil is of the standard Gulf Coast grade, ranging about 22° Baumé gravity. Development has spread principally to the south and slightly to the north from the discovery well. Its trend is in a line parallel with the edge of the dome as outlined in the paper, and at a distance of about 2,000–2,500 feet from it.

The initial production of the wells range from 500 to 4,000 barrels each. The producing formation is about 100 feet thick, ranging about 3,400–3,600 feet in depth. The productive formation is a fine-grained quartz sand of Oligocene age. There is apparently a shear zone in the immediate vicinity of the dome where the Eocene formations have been pushed up. Wells drilled in this zone are small producers of 10–20 barrels per day of about 38° Baumé gravity oil.

GEOLOGICAL NOTES

AN INCLUSION OF PETROLEUM IN A FOSSIL CAST

Near the west edge of Bloomington, Indiana, at a point where the St. Louis limestone (Mitchell limestone of Indiana authors) is being quarried, there are many casts of gastropods which contain petroleum. The oil appears to be of fairly high gravity and has a green color. The fossil casts are about one-half inch in diameter and there are a few drops of oil in nearly every one. In some cases the oil is dispersed from the cast to the surrounding rock where it is most porous. The oil is believed to be indigenous to the fossil, as it does not appear to have come from any other source.

The St. Louis formation in this locality is a close-grained, hard, light-gray limestone of Mississippian (Meramecian) age about 200 feet thick. The basal St. Louis contains "showings" of oil in a number of localities in southern Indiana, though none of them are of such significant interest as this.

John R. Reeves

Oil Hill, Kansas

AN AID TO THE STUDY OF FORAMINIFERA

In the study of Foraminifera, one of the tasks confronting the investigator involves the problem of isolating the various species discovered and filing them away for future reference. Various methods have been developed that range from the placing of the fossils loosely in a "depressed" slide to attaching each individual to the end of a needle and sealing the needle in a cell formed by boring a hole in a piece of wood. The first and simplest method is rather unsatisfactory from many standpoints, the two main objections being: (*a*) the bottom of the "depressed" slide is not flat, but concave, and (*b*) but one cell occurs on each slide. The complicated construction and the time-consuming effort involved in attaching a tiny foram to the point of a needle form the principol objections to the second method of mounting.

During a recent study of Foraminifera at the University of Chicago, Mr. A. W. Slocom and the writer devised a slide that is exceedingly simple and remarkably efficient in several ways.

Celluloid is soluable in acetone and when moistened with that liquid develops the power of adhering tightly to any surface to which it may be applied. If a strip of celluloid is cut 24 mm.×60 mm., holes may be punched in it about 4 mm. in diameter and the strip then cemented to an ordinary biological microscope slide in such a position that the slide will readily fit into an ordinary slide-filing cabinet and carry a necessary label nicely. The holes may be punched in the strip of celluloid with an ordinary paper punch at any desired distance apart. The celluloid strip is cemented to the glass foundation slide by moistening both with acetone and then pressing them firmly together. Each of the cells thus formed by the holes in the celluloid may receive one or more specimens of forams representing individuals of a single species. These individuals may be left loose in their cells or may be cemented to the underlying glass in such a position that two or more definite views are exposed for study.

After placing the desired number of forams in these cells, a thin cover-glass, 24 mm.×60 mm., is cemented firmly over the entire strip of celluloid by moistening the cover-glass with acetone and applying it immediately to the celluloid. The slide should be set aside under a light load to hold the cover-glass firmly against the celluloid till the acetone has all evaporated. This will take but an hour or so. The slide is then ready for filing as a part of a permanent record.

The writer has placed as many as thirty cells on a single slide, but finds that sixteen is a desirable number, for there is room for a numerical label below each cell when the cells are not crowded. This label can be put on the celluloid with India ink before sealing on the cover-glass, and a card index filled out giving the name of the foram in each cell with the numbers on the card and beneath the cell corresponding.

If the foram lies loose in the cell, it may be studied either through the cover-glass or through the slide itself; if cemented to the basal slide, it can be studied only through the cover-glass.

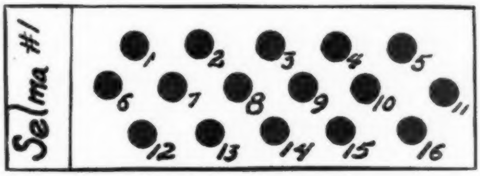
In the type of slide just described, the base is so nearly the same thickness that each individual thereon can be brought into focus under the microscope by using only the fine-adjustment screw. This cell system also possesses the advantage of gathering together, on a single slide, sixteen or more different species of forams, in many cases representing the entire fauna recovered from a horizon.

The finished slide is illustrated in the accompanying figure.

The thickness of the celluloid strips used will depend on the size of the forams. Celluloid sheets may be purchased in almost any desired thickness. If unusually large minutiae are to be preserved, two or more

strips of the celluloid may be cemented together with acetone before holes are punched in it. The strips may be cut from the sheet celluloid into the required size by means of the ordinary knife used for trimming photographic prints, etc.

Slides of this type are also of value in studies of sedimentation when it is desirable to preserve sand grains, etc., typical of certain definite horizons. The sand grains may be classified as to kind of material composing them, according to size, etc. The preservation of sands on such a



slide makes them always available for comparative studies when new or unknown formations are under investigation.

The above suggestion is given out to co-workers on minutiae with the idea that it may facilitate the handling of the little forams and aid in the efficient collection of known faunal groups, characteristic sediments, etc., so they may be utilized quickly and accurately for reference and comparison with unknown types.

E. T. Thomas

University of Chicago
March, 1925

GEOPHYSICAL METHODS IN THE GULF COASTAL PLAIN

In connection with a recent note calling the attention of American geologists to the possibility of profitable use of geophysical methods in areas such as the Gulf Coastal plain, the following historical note may be of interest.

At the time that note was written, September, 1924, nine or more Eötvös torsion balances, several German seismographs, and at least one magnetic balance were at work; a seismographic method of American design had just been tried out; the geologic department of the Rycade Oil Corporation had already discovered one new salt dome chiefly by means of the Eötvös torsion balance, the German geophysicists of the Gulf Production Company were on the point of discovering two more salt domes by means of the seismograph and Eötvös torsion balance, and

the companies using the geophysical methods had several dome prospects, which have not as yet been drilled.

The Eötvös torsion balance was invented over thirty years ago, and the possibility of its applicability in geological work was proved some twenty years ago. Yet it seems almost entirely to have escaped the attention of American geologists and geophysicists. The writer's chief, Mr. E. L. DeGolyer, made an attempt in 1914 to secure an Eötvös torsion balance but was forestalled by the war and was not able to get instruments delivered in this country until October, 1922. He had sent the writer to Europe in the summer of that year in connection with the torsion balance and other geophysical methods. The first field observation with the torsion balances was taken by the writer and an assistant in December, 1922. One of the two instruments was soon sent to the Mexican Eagle for work in the salt-dome region in Mexico. The Royal Dutch Shell, which had been using the Eötvös torsion balance in Egypt, about the same time sent torsion-balance parties to the Roxana Petroleum Corporation for use in the Texas-Louisiana salt-dome area and to the Mexican Eagle for use in Mexico. An expedition of a German seismologic company was sent to Mexico early in the summer of 1923 by the Mexican Eagle to try out the seismographic method on the Tamasopo structural ridge. Later in the summer the same German company persuaded the Marland Oil Company to try out this method in the northern extension of the Mexia-Powell zone of faulting. The first important discovery of a structure was made in February, 1924, by the Rycade Oil Corporation, in locating the Nash salt dome during the course of an Eötvös torsion balance survey of a sulphur-water locality. In the spring of 1924, several of the German geophysical companies sent representatives to this country, and later expeditions were organized. The Gulf Production Company and, much later in the year, the Texas Company engaged German torsion balance expeditions for use in the Gulf Coast, and the former company and the Marland Oil Company both put German seismographic expeditions in the field in the Gulf Coast. In the summer, an American seismographic method, which had previously been tried out in Oklahoma, was tested on the Pierce Junction salt dome by the Atlantic Oil and Refining Company, and is now being used in Mexico. In October and November, 1924, the German geophysicists of the Gulf Production Company discovered two new salt domes—the Orchard dome entirely on the basis of seismographic work and the Long Point dome on the basis of torsion balance work checked by seismographic work. The companies using the geophysical methods have several prospective salt domes which have not

been drilled. The Royal Dutch Shell is reported to be experimenting with a torsion balance in California. Several oil companies now have physicists on their staffs and are actively considering geophysical methods for geologic work.

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HOUSTON, TEXAS
March, 1925

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BERTRAND L. JOHNSON, L. M. JONES, AND M. F. MCSHEA

THE ASSOCIATION ROUND TABLE

THE WICHITA MEETING OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, MARCH 26, 27, 28, 1925

In accordance with custom now established, it is desirable, for the benefit of the considerable portion of our increasingly large membership which was unable to be present in person, as well as for convenient historical record, to publish in the *Bulletin* a brief account of the TENTH ANNUAL CONVENTION of the Association, held at Wichita, Kansas, March 26, 27, 28, 1925. What has been said of previous meetings as to increase in size and general interest is applicable to the Wichita meeting, for as the Association grows it appears that each of the annual meetings becomes more important and more worth while. Attendance at the convention appears increasingly a privilege which is well worth the aggregate thousands of miles of travel and other expenses which are entailed.

Long before even the first visitor arrived, reservations of rooms had been arranged by the local committee and, by means of a very convenient and efficient arrangement in the lounge room of the lobby floor of the Hotel Lassen, the business of registration was very quickly attended to. Detailed printed announcements concerning convention activities in general, a program of the technical sessions, accompanied by abstracts of papers to be presented, prospectuses and announcements concerning field trips, and various other conveniences were here readily available to visiting members and guests. Railway certificates filed with the committee shortly assured special-rate return fares from Wichita.

Technical and business sessions of the Association were held in the very commodious and well-appointed clubroom of the newly constructed Elks Club building across the street from the Lassen Hotel, the arrangement here proving adequate and admirable in every way for the requirements of this most important part of the convention. After addresses of welcome to Wichita by Earl C. Elliott, city manager, and William L. Ainsworth, president of the Kansas Geological Society, and a response by President James H. Gardner of the American Association, the technical program got under way, beginning with the papers on Kansas and Oklahoma. Through this and practically all of the subsequent sessions, the large auditorium, which seemed to have much more than needed capacity, was entirely filled. The summary of the technical program is given on following pages.

At the business session on Thursday morning reports by the officers of the Association were submitted, and new officers for the year 1925–26 were elected: E. L. DeGolyer, of New York City, president; R. S. McFarland, of Tulsa, vice-

president; C. E. Decker, Norman, Oklahoma, secretary-treasurer; and Raymond C. Moore, Lawrence, Kansas, editor. As customary, a special committee for consideration of general business to be brought before the Association at its ensuing business session was appointed by the president.

On Thursday evening the convention enjoyed a very scholarly and very interesting public address delivered by its specially honored guest, Dr. John M. Clarke, distinguished state geologist of New York. This lecture was given in the capacious Arcadia Theater to a large and appreciative audience. Later there was a pleasurable informal dance in the ballroom of the Lassen Hotel, which, while not scheduled on the program, was enjoyed by many of the Association members and their guests.

Presentation of technical papers and discussion occupied all of Friday's program, but shortly before noon, a considerable number of the members in attendance left in order to participate in a specially arranged field trip to the El Dorado oil field, a short distance east of Wichita. This trip, planned to cover thoroughly the many points of interest in the El Dorado field, took up most of the afternoon. Automobile transportation was furnished by the Wichita Oil Men's Club and Civic Club and individuals co-operating with the Wichita Chamber of Commerce. Upon arriving at Oil Hill, the party was served a box lunch by the Empire Gas and Fuel Company. Although ideal weather conditions and the interesting announced itinerary for the trip attracted a very large number, there was hardly a noticeable diminution in attendance at the technical sessions of the afternoon.

The annual banquet of the Association was held in the Rose Room of the Forum Building, a mammoth room which had been beautifully decorated for the occasion. If possible, the gathering was even more pleasant in many ways than similar functions of the past. Dr. D. W. Ohern acted in his usual able manner as toastmaster, but seemed measurably to derive a certain inspiration from his delightful propinquity to a special guest at the banquet, Queen Petrolia, Miss Ramona M. Trees, who had been Princess Kansas at the Petroleum Exposition at Tulsa in the fall. The chief speaker at the banquet was Mr. W. C. Franklin, president of the Mid-Continent Oil and Gas Association, who talked on the subject, "Some Problems of the Petroleum Industry." After the banquet and the customary post-prandial exercises, the gathering adjourned to the adjacent Arcadia Theater, where a series of ingenious and interesting theatrical skits prepared by various local geological groups kept the audience in an uproar. During the period of theatrical divertissement the banquet room was cleared and the floor prepared for dancing. With splendid music the former banquet hall, now ballroom, was a lively scene until two in the morning.

Saturday was occupied by technical sessions and by the final business meeting. For the ensuing Monday, field trips to the salt mines at Lyons, Kansas, and to the Russell oil field had been arranged by the local committee.

One very commendable and much appreciated feature of the Wichita con-

vention was the large exhibit room and the facilities for display of large-scale geologic and structural maps and all manner of geological and scientific exhibits. Supplementing in an effective way the material offered in the technical sessions, this is a feature which certainly should persist and should form an important part of arrangements for succeeding conventions.

A varied and interesting program of entertainment for the ladies was provided at Wichita. It is reported that it was of such attractiveness that some of the ladies who are also members of the Association found it very difficult to attend the technical sessions. A novel and commendable arrangement of the local committee was provision of a children's playroom and nursery in the Lassen Hotel, where a nurse was in charge to look after children of visitors at the convention.

According to reliable testimony, most of the credit of the very successful handling of the Wichita convention goes to the general chairman of the local committee, Marvin Lee. However, he was very ably assisted by each of the chairmen of the committees. These committees of the Kansas Geological Society committee of arrangements are as follows:

KANSAS GEOLOGICAL SOCIETY COMMITTEE OF ARRANGEMENTS

General Chairman, Marvin Lee

Kansas Program.—E. W. Scudder, *chairman;* William L. Ainsworth, Fritz Aurin, Everett Carpenter, Raymond M. Carr, D. P. Dean, Henry A. Ley, Raymond C. Moore, William L. Stryker, M. M. Valerius, Fred K. Foster.

Arrangements.—William L. Ainsworth, *chairman;* Amil A. Anderson, Edwin N. Carlson, Everett Carpenter, Justus H. Cline, Charles M. Coats, F. H. Holl, Charles E. Straub, C. R. Thomas.

Hotels.—C. R. Thomas, *chairman.*

Reception.—Justus H. Cline, *chairman;* H. J. Allen, A. M. Meyer, Shamus O'Brien, Roy A. Reynolds, Byron Rife, C. B. Taylor, F. A. Oyster.

Publicity.—By Arrangements Committee.

Banquet.—Charles E. Straub, *chairman;* George A. Forrester, J. L. Garlough, Walter W. Larsh, Warren H. Thralls, Francis Krone.

Field Trip.—F. G. Holl, *chairman;* David Ainsworth, James Russell Crabtree, Huntsmen Haworth, L. C. Hay, Charles C. Hoffman, John R. Reeves, L. A. Ogden, H. A. Scott, H. R. Woodward.

Ladies' Entertainment.—Edwin N. Carlson, *chairman; Reception:* Mrs. William L. Ainsworth, Mrs. F. L. Aurin, Mrs. F. C. Holl, Mrs. Marvin Lee; *Registration:* Mrs. Amil A. Anderson, Mrs. T. M. Cady, Mrs. Charles M. Coats, Mrs. J. L. Garlough, Mrs. Walter W. Larsh, Mrs. J. R. Reeves, Mrs. H. A. Scott; *Luncheon:* Mrs. H. J. Allen, Mrs. Everett Carpenter, Mrs. George A. Forrester, Mrs. F. K. Foster, Mrs. Francis Krone, Mrs. L. A. Ogden, Mrs. C. E. Straub.

Finance.—Charles M. Coats, *chairman;* Fritz Aurin, Justus H. Cline, Everett Carpenter, George A. Forrester, Henry A. Ley, E. W. Scudder, Charles W. Studt.

Entertainment.—Amil A. Anderson, *chairman;* George H. Bruce, Glen C. Clark, Arthur Truex.

PROGRAM

ADDRESSES OF WELCOME:

On behalf of the city of Wichita: EARL C. ELLIOTT, city manager

On behalf of the Kansas Geological Society: WILLIAM L. AINSWORTH, president

RESPONSE:

JAMES H. GARDNER, president, American Association of Petroleum Geologists

KANSAS

Exploration for Oil in Kansas, RAYMOND C. MOORE

Structural Conditions in the Vicinity of the Igneous Intrusive in Clay County, Kansas, MARVIN LEE

The Subsurface Geology of Wilson County, Kansas, W. L. STRYKER

Geology of Russell County, Kansas, Both Surface and Subsurface, M. M. VALERIUS

General Structural Conditions in Kansas and Some Type Structures, E. W. SCUDDER

Significance of Some of the Surface Structures of Central and Western Kansas, W. H. TWENHOFEL

Origin of Anticlines in Benton Shale Area of Western Kansas, C. R. THOMAS

The Subsurface Distribution of the Comanchean of Western Kansas, W. H. TWENHOFEL AND W. L. STRYKER

The Dakota Formation of Kansas, A. C. TESTER

Rainbow Bend Field, Cowley County, Kansas, D. R. SNOW and D. P. DEAN

Observations and Problems concerning "Shoestring" Oil and Gas Pools of Eastern Kansas, JOHN L. RICH

The Producing Sand of the Thrall-Burkett-Seeley Fields, Greenwood County, Kansas, RAYMOND M. CARR

New Data on the Comanchean Strata of Central Kansas, W. H. TWENHOFEL and A. C. TESTER

OKLAHOMA, TEXAS, AND ADJACENT STATES

Suggestions concerning the Probable Subsurface Structure of the High Plains of Western Texas as Deduced from Observations of the Surface in Trans Pecos, Texas, W. A. J. M. VAN DER GRACHT

The Lower Permian of Northern Oklahoma, F. L. AURIN and G. C. CLARK

The Subsurface Stratigraphy of Western Oklahoma, FRANK C. GREENE

Wilcox Sand Production, Tonkawa Field, GLENN C. CLARK

Areal Extent and Stratigraphy of the Whitehorse Sandstone, R. L. CLIFTON

Relationship of Mountain Folding to the Oil and Gas Structures of Southern Oklahoma, C. M. BECKER

A Peculiar Faulted Area at the Southeast End of the Anadarko Basin, J. V. Howell

The San Angelo Formation in Texas and Its Probable Extension in Oklahoma, J. W. Beede and D. D. Christner

Geology and Oil Fields of Archer County, Texas, W. E. Hubbard, W. C. Thompson

Some Notes on the Permian of New Mexico and Arizona, N. H. Darton

The Subsurface Geology of the Reagan County, Texas, Oil Field, E. H. Sellards and L. T. Patton

Further Notes on the Currie Field in Navarro County, Texas, F. H. Lahee

The Age of the Chalk at White Cliffs, Arkansas, Alva C. Ellisor

Some Occurrences of Radiolaria in Texas Sediments, Johan A. Udden

The Luling Field, Caldwell and Guadalupe Counties, Texas, Ernest W. Brucks

A Notable Unconformity in the Permian of North Texas, Clifton W. Clark

The Wortham, Texas, Oil Field, H. C. O. Clarke, P. T. Seashore, and S. A. Judson

Volcanic Ash: A Possible Key Bed in Louisiana and Arkansas, H. D. Easton

The Subsurface Structures of Northeastern Oklahoma, T. W. Thom, Jr.

The Springer Member of the Glenn Formation at Ardmore, Oklahoma, James A. Waters

The Origin of the Faults in Osage and Creek Counties, Oklahoma, Lyndon L. Foley

The Papoose Pool, Harry H. Nowlan

The Cromwell Oil Pool, L. G. Keppler, G. A. Kroenlein, and A. W. Lauer

The Permian Formations of Kansas, Oklahoma, and Northern Texas, C. N. Gould

Possible Correlations of Producing Sands of the Hewitt and Graham Fields, Carter County, Oklahoma, Willis Storm

Volcanic Rock in Another Producing Well near Litton Springs, Texas, H. P. Bybee and M. A. Hanna

ROCKY MOUNTAIN REGION

A Study of Some Upper Cretaceous Diastrophism and Sedimentation in Montana, A. A. Hammer and A. M. Lloyd

Some Features of Red-Bed Bleaching in Southern Montana, Gail F. Moulton

Big Lake Field, Lake Basin District, Montana, A. Max Bauer

Some Structural Problems in Northwestern South Dakota, Roy A. Wilson

Faulting in the Rocky Mountain Region, J. S. Irwin

Correlations in Eastern Utah and Western Colorado, Glen M. Ruby

The Occurrence of Black Oil in Wyoming, John G. Bartram

The Probable Origin of Some Gypseous Oil-bearing Rocks in Wyoming, W. W. Rubey

CALIFORNIA

Calcium Chloride Waters from Certain Oil Fields in Ventura County, California, N. L. TALIAFERRO and F. S. HUDSON
The Age and Correlation of the Kreyenhagen Shale in California, G. D. HANNA
Structural Problems in Southern California, W. S. W. KEW
Unconformity between the Santa Margarita and Monterey Formations in the Salinas Valley, R. D. REED
Notes on the Geology of the Baldwin Hills Region, A. J. TIEJE
The Wheeler Ridge Oil Field, GEORGE CUNNINGHAM

CENTRAL AND EASTERN UNITED STATES

New Tinsleys Bottom Pool on the Jackson-Clay County Line in Tennessee, W. A. NELSON
Carbon Ratios and Petroleum in Illinois, GAIL F. MOULTON
The Oil Fields of New York State, C. A. HARTNAGEL
Paleontology of the Lower Mississippian in Missouri and Adjoining States, E. B. BRANSON

FOREIGN

Geology and Oil Products of the Tzetiutsing District, Szechuan, China, G. D. LOUDERBACK
Chinese Methods of Well-Drilling and of Handling Brines and Gas, G. D. LOUDERBACK
The Permian of India, DALE D. CONDIT
Geological History of the Panuco River Valley with a Discussion of Dynamics Involved and Their Relation to the Origin of Oil in Mexico, EARL A. TRAGER
The Status of Americans in Petroleum Developments in Europe and Asia, JOHN W. FINCH
Geology and Oil Resources of Trinidad, B. W. I., G. A. WARING and C. G. CARLSON
A Geological Reconnaissance in South and East Central Brazil with Notes on the Natural Resources and Industries of Brazil, H. W. C. PROMMEL
The Permian of the St. Lawrence Region, HUGH MACKAY

SPECIAL AND TECHNICAL

Oil-Field Developments and Paleontology, DAVID WHITE
Laboratory Petroleum Decline Curves, L. C. MORGAN
Some Paleontological Problems in Connection with Devonian, Mississippian and Pennsylvania Rocks, E. B. BRANSON
An Experimental Study of the Origin of Salt Domes, PAUL D. TORREY and C. E. FRALICH
Results of Core Testing of Kansas Shallow Sands and Suggestions as to Possibilities of Petroleum Recovery by Mining Methods, JOHN L. RICH

Oil Mining, EDWARD BLOESCH
Correlation of Oil Sands by Sedimentary Analysis, M. E. MORTIMORE
The Elements of the Oil-Well Spacing Problem, L. C. UREN
A Critical Examination of the Equal Pound Loss Law for Gas Reserves, R. H. JOHNSON
A Second Study in the Age-Size Method of Constructing Composite Decline Curves, R. H. JOHNSON
The Relation of Oil Shale to Petroleum, F. M. VAN TUYL
Sources of Material from Which Petroleum May Have Been Derived, JUNIUS HENDERSON
Some Experimental Work Testing the Hydraulic Theory of Oil Migration and Accumulation by Means of the Downward Circulation of Water, ALBERT W. WEEKS
The Petrography and Origin of Gypsum and Anhydrite Deposits, MARCUS I. GOLDMAN
The Application of the Alignment Chart to Petroleum Engineering, R. W. PHELPS and F. W. LAKE
The Torsional Balance of Baron R. von Eotvos, by Dr. D. Pekar, A. WROBLEWSKI
An Eocene Fauna from the Moctezuma River, Mexico, JOSEPH A. CUSHMAN

According to the records of the secretary, a total of 438 members registered at the Wichita meeting. This is 133 more than attended the meeting at Houston last year. There were 233 registered visitors and 154 ladies. The list of members attending is as follows.

MEMBERS REGISTERED AT TENTH ANNUAL MEETING OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, WICHITA, KANSAS, MARCH 26–28, 1925

Absher, William F., Norman, Okla.
Ainsworth, David, Wichita, Kan.
Ainsworth, William L., Wichita, Kan.
Allen, W. J., Tulsa, Okla.
Allison, A. P., Tulsa, Okla.
Ambrose, A. W., Bartlesville, Okla.
Ames, E. W., Dallas, Tex.
Anderson, Amil A., Wichita, Kan.
Anderson, Carl B., Tulsa, Okla.
Armstrong, J. M., Tulsa, Okla.
Aronson, Sam M., Dallas, Tex.
Atkinson, William H., Oklahoma City, Okla.
Aurin, F. L., Ponca City, Okla.
Austin, P. H., Tulsa, Okla.

Baker, R. F., Houston, Tex.
Baldwin, Harry L., Jr., Denver, Colo.
Bale, Hubert E., Ponca City, Okla.
Barbour, Erwin H., Lincoln, Neb.
Barrett, W. G., Madison, Wis.
Bartlett, F. W., Tulsa, Okla.
Barton, Donald C., Houston, Tex.
Bartram, John G., Casper, Wyo.
Barwick, John S., Bartlesville, Okla.
Bass, N. W., Lawrence, Kan.
Bauer, C. Max, Billings, Mont.
Beck, Elfred, Denver, Colo.
Becker, Clyde M., Chickasha, Okla.
Beede, J. W., San Antonio, Tex.

Beekley, A. L., Tulsa, Okla.
Belford, L. S., El Dorado, Kan.
Berger, Walter R., Houston, Tex.
Birk, R. A., Ardmore, Okla.
Blanchard, W. Grant, Denver, Colo.
Bloesch, Edward, Tulsa, Okla.
Bostick, J. Wallace, Dallas, Tex.
Boyle, A. C., Jr., Laramie, Wyo.
Bradish, Ford, Breckenridge, Tex.
Bradley, E. L., Emporia, Kan.
Brainerd, A. E., Denver, Colo.
Branner, George C., Little Rock, Ark.
Brauchli, Rudolf, Tulsa, Okla.
Brockway, E. R., Marshall, Ill.
Brown, J. Earle, Tulsa, Okla.
Bruce, George H., Oil Hill, Kan.
Brucks, E. W., Luling, Tex.
Bruyere, Alan, Wichita, Kan.
Buchanan, George S., Tulsa, Okla.
Burchfiel, H. L., San Francisco, Calif.
Burley, J. E., Washington, D. C.
Burt, Roy A., Kansas City, Mo.
Burton, George E., Ardmore, Okla.
Butcher, S. D., Ponca City, Okla.
Buttram, Frank, Oklahoma City, Okla.
Bybee, Hal P., Austin, Tex.

Cadman, W. K., Eureka, Kan.
Cady, Gilbert H., Fayetteville, Ark.
Cannon, R. L., Austin, Tex.
Carlson, C. G., Ishpeming, Mich.
Carlson, Edwin N., Wichita, Kan.
Carney, Frank, Wichita Falls, Tex.
Carpenter, Everett, Winfield, Kan.
Carpenter, Marble J., Bartlesville, Okla.
Cartwright, Lon D., San Angelo, Tex.
Caudill, Samuel J., Tulsa, Okla.
Cheney, M. G., Graham, Tex.
Cheyney, A. E., Tulsa, Okla.
Christner, D. D., Dallas, Tex.
Clark, C. W., Wichita Falls, Tex.
Clark, Frank R., Tulsa, Okla.
Clark, Frank T., Bartlesville, Okla.
Clark, Glenn C., Ponca City, Okla.
Clark, Howard, Tulsa, Okla.
Clark, Stuart K., Ponca City, Okla.
Clark, W. C., Ardmore, Okla.
Clarke, Carl W., Tulsa, Okla.
Cline, Justus H., Wichita, Kan.
Clinkscales, Albert S., Vinita, Okla.
Clowe, Charles E., Ardmore, Okla.
Coats, Charles M., Wichita, Kan.
Collingwood, D. M., Dallas, Tex.
Collins, Melvin J., Midland, Tex.
Collom, Roy E., Berkeley, Calif.
Conkling, R. A., Oklahoma City, Okla.
Corbett, C. S., Lawrence, Kan.
Coryell, Lewis S., Bristow, Okla.
Cottingham, V. E., Ada, Okla.
Crider, A. F., Shreveport, La.
Crum, H. E., Emporia, Kan.
Cullen, R. J., Tulsa, Okla.
Cumming, Alfred, Tulsa, Okla.

Dakin, Francis W., Oklahoma City, Okla.
Dally, Claude F., Tulsa, Okla.
Daniels, H. G., Okmulgee, Okla.
Daniels, James I., Dallas, Tex.
Dat, C. O., Shreveport, La.
Davies, Fred A., Denver, Colo.
Davis, Robert J., Tulsa, Okla.
Dawson, Joseph M., San Antonio, Tex.
Dean, D. P., Tulsa, Okla.
Dean, Paul C., Tulsa, Okla.
Decker, C. E., Norman, Okla.
DeGolyer, E., New York, N. Y.
Denison, A. R., Norman, Okla.
Deussen, Alexander, Houston, Tex.
DeWolf, Frank W., Dallas, Tex.
Dodson, Floyd C., San Angelo, Tex.
Donoghue, David, Houston, Tex.
Donovan, P. W., Minneapolis, Minn.
Dorsey, George Edwin, Tulsa, Okla.
Dott, Robert H., Tulsa, Okla.
Doub, Charles O., Independence, Kan.
Douglas, James M., Fort Collins, Colo.
Duce, James T., New York, N. Y.
Dugan, Ira E., Ponca City, Okla.
Dunlap, Gilmore S., Tulsa, Okla.
Dunlevy, Robert B., Winfield, Kan.
Duston, A. W., Okmulgee, Okla.

Ebmeyer, G. E., Arkansas City, Kan.
Edson, Fanny C., Tulsa, Okla.
Edson, Frank, A., Norman, Okla.
Edwards, O. M., Tulsa, Okla.
Egan, J. A., Tulsa, Okla.
Ellisor, Alva C., Houston, Tex.
Erwin, Andrew U., Tulsa, Okla.
Evans, Noel, Ponca City, Okla.

Ferguson, John L., Cisco, Tex.
Finch, John W., Denver, Colo.
Floyd, F. W., Tulsa, Okla.
Foley, L. L., Tulsa, Okla.
Ford, Carl S., Enid, Okla.
Forrester, George A., Wichita, Kan.
Foster, Fred K., Winfield, Kan.

Galbraith, T. J., San Francisco, Calif.
Gallagher, William G., Shawnee, Okla.
Gardner, James H., Tulsa, Okla.
Garrett, M. M., Wichita Falls, Tex.
Garrett, Robert E., Tulsa, Okla.
Gaylord, E. G., San Francisco, Calif.
Geis, W. H., Casper, Wyo.
George, H. C., Norman, Okla.
Gester, G. C., San Francisco, Calif.
Giffin, Wilson C., Long Beach, Calif.
Gish, Wesley G., Tulsa, Okla.
Goodrich, R. H., Houston, Tex.
Gordon, Dugald, Dallas, Tex.
Gouin, Frank, Tulsa, Okla.
Gould, Charles N., Norman, Okla.
Green, Guy E., Austin, Tex.
Greene, Frank C., Tulsa, Okla.
Griley, H. L., Tulsa, Okla.
Griswold, C. T., Raton, N. M.
Gunby, Merle F., Chanute, Kan.

Hagan, A. M., Fort Worth, Tex.
Hall, Ellis A., Boulder, Colo.
Hall, Roy H., Denver, Colo.
Hamilton, C. W., New York, N. Y.
Hamilton, W. R., Tulsa, Okla.
Hammer, A. A., Billings, Mont.
Hares, C. J., Denver, Colo.
Harkness, Robert B., Toronto, Can.
Harlowe, Leslie S., Shreveport, La.
Harnsberger, T. K., Tulsa, Okla.
Harrison, Thomas S., Denver, Colo.
Haworth, Erasmus, Lawrence, Kan.
Haworth, Huntsman, El Dorado, Kan.
Hay, Laurence C., El Dorado, Kan.
Heald, K. C., New Haven, Conn.
Heaton, R. L., Denver, Colo.
Henderson, H. H., San Angelo, Tex.
Henderson, Junius, Boulder, Colo.
Hendrickson, Victor J., Denver, Colo.
Hennen, Ray V., Pittsburgh, Pa.
Henniger, W. F., Houston, Tex.
Herald, Frank A., Tulsa, Okla.
Herald, John M., Tulsa, Okla.
Heroy, William B., New York, N. Y.
Hindes, E. P., Bartlesville, Okla.
Hintze, F. F., Denver, Colo.
Hoffer, Clarence W., Olney, Tex.
Hoffman, Charles C., El Dorado, Kan.
Hoffman, Malvin G., Tulsa, Okla.
Holl, Frederic G., El Dorado, Kan.
Holman, Eugene, Shreveport, La.
Honess, Charles W., Bartlesville, Okla.
Hoover, James E., Tulsa, Okla.
Hopper, Walter E., Shreveport, La.
Hotchkin, Harry, Tulsa, Okla.
Housh, C. N., Houston, Tex.
Howell, J. V., Wichita Falls, Tex.
Howendobler, John L., Tulsa, Okla.
Hudson, Frank S., Los Angeles, Calif.
Hughes, C. Don, Duncan, Okla.
Hughes, Richard, Tulsa, Okla.
Hughes, Urban B., Vernon, Tex.
Hummell, H. L., Wichita, Kan.
Hutson, E. B., Bartlesville, Okla.
Hyde, Clarence E., Houston, Tex.

Irwin, Joseph S., Denver, Colo.
Isenberger, N. P., Winfield, Kan.
Ivy, John S., Shreveport, La.

Jennings, Charles I., Denver, Colo.
Jensen, Joseph, Los Angeles, Calif.
Johnson, Roswell H., Pittsburgh, Pa.
Jones, Boone, Blackwell, Okla.
Jones, Edward L., Jr., Ponca City, Okla.
Jones, R. D., Tulsa, Okla.
Judson, Sidney A., Dallas, Tex.

Keeler, W. W., Tulsa, Okla.
Kendrick, Frank E., Dallas, Tex.
Kennedy, L. E., Tulsa, Okla.
Keppler, L. G., Tulsa, Okla.
Kernan, Thomas H., Dallas, Tex.
Kesler, L. W., Winfield, Kan.
Kinkel, W. C., Holdenville, Okla.
Kite, W. C., Oklahoma City, Okla.
Knappen, Russell S., Lawrence, Kan.
Kniker, Hedwig T., Houston, Tex.
Kolm, Robert N., Wichita Falls, Tex.
Kraus, Edgar, Enid, Okla.
Kroenlein, George A., Tulsa, Okla.

Lahee, Frederic H., Dallas, Tex.
Lane, Laura Lee, Houston, Tex.
Langworthy, A. A., Tulsa, Okla.
Lee, Huylar W., Wichita Falls, Tex.
Lee, Marvin, Wichita, Kan.
Lee, Wallace, Pecos, Tex.
Leighton, M. M., Urbana, Ill.
Levorsen, A. Irving, Okmulgee, Okla.
Lewis, J. Whitney, Tulsa, Okla.
Ley, Henry A., Tulsa, Okla.
Lilligren, J. M., Garnett, Kan.
Lindeblad, Elmer E., Bartlesville, Okla.
Lloyd, A. M., Billings, Mont.
Lloyd, E. Russell, Denver, Colo.
Longyear, Robert D., Minneapolis, Minn.
Lounsbery, D. E., Denver, Colo.
Lovejoy, John M., Tulsa, Okla.
Lupton, Charles T., Denver, Colo.
Lynn, Robert H., Holdenville, Okla.
Lyons, Richard T., Tulsa, Okla.

McCoy, Alex W., Denver, Colo.
McDonald, O. G., Tulsa, Okla.
McDonald, Worth W., Shreveport, La.
McFarland, R. S., Tulsa, Okla.
Mackay, Hugh, Sapulpa, Okla.
McLaughlin, Homer C., Duncan, Okla.
McNeely, Robert, Ponca City, Okla.
McNeese, Charles H., Ponca City, Okla.
McWhirt, Burr, Tulsa, Okla.
Markham, Edmond O., Denver, Colo.
Markley, Elmer A., Tulsa, Okla.
Marshall, Earl E., El Dorado, Kan.
Martin, George C., Washington, D.C.
Mason, S. L., Houston, Tex.
Masterson, Reba B., Houston, Tex.
Matson, George C., Tulsa, Okla.
Meland, Norman, Oklahoma City, Okla.
Melcher, A. F., Ponca City, Okla.
Mendendall, W. C., Washington, D.C.
Merritt, J. W., Tulsa, Okla.
Meyer, A. M., Tulsa, Okla.
Millar, John E., Bristow, Okla.
Miller, E. F., Denver, Colo.
Miller, Forrest J., Shreveport, La.
Miller, W. Z., Tulsa, Okla.
Miller, Willard L., Oklahoma City, Okla.
Millikan, C. V., Tulsa, Okla.
Miser, H. D., Washington, D. C.
Mitchell, R. C., Tulsa, Okla.
Mohr, C. L., Denver, Colo.
Moncrief, Ernest C., Wichita, Kan.
Moore, Raymond C., Lawrence, Kan.
Morris, A. F., Bartlesville, Okla.
Mortimore, M. E., Iowa City, Ia.
Moser, G. E., Bartlesville, Okla.
Moulton, Gail F., Urbana, Ill.
Munson, H. E., Winfield, Kan.
Mylius, L. A., St. Louis, Mo.

Neumann, L. Murray, Tulsa, Okla.
Newby, Warner, Ponca City, Okla.
Nisbet, J. M., Bartlesville, Okla.
Nolan, E. D., Los Angeles, Calif.
Nolte, W. J., Wichita Falls, Tex.
Nowlan, Harry H., Tulsa, Okla.

Oakes, M. C., Norman, Okla.
O'Brien, Shamus, Florence, Kan.
Officer, H. G., Enid, Okla.
Ogden, Laurence A., Oil Hill, Kan.
Ohern, D. W., Oklahoma City, Okla.
Oles, L. M., Independence, Kan.
Orynski, Leonard W., Colorado, Tex.
Osborne, Robert R., Tulsa, Okla.
Ott, Emil, San Angelo, Tex.
Owen, E. W., Garnett, Kan.
Oyster, F. A., Independence, Kan.

Page, J. H., Iola, Kan.
Parker, E. C., Ponca City, Okla.
Paschal, E. A., Oklahoma City, Okla.
Patton, Leroy T., Austin, Tex.
Peabody, H. W., Stillwater, Okla.
Pease, C. C., Topeka, Kan.
Perini, V. C., Jr., Wichita Falls, Tex.
Perkins, Joseph M., Oklahoma City, Okla.
Perrine, Irving, Oklahoma City, Okla.
Phelps, Robert W., Brea, Calif.
Philbrick, E. P., Denver, Colo.
Pishny, C. H., Ponca City, Okla.
Plummer, F. B., Houston, Tex.
Pogue, Joseph E., New York, N. Y.
Potter, G. C., Tulsa, Okla.
Poulsen, Frank E., Mexia, Tex.
Powers, Sidney, Tulsa, Okla.
Pratt, Ernest S., Ponca City, Okla.
Pratt, Wallace E., Houston, Tex.
Price, S. S., Tulsa, Okla.

Quiett, Roy C., Wichita, Kan.

Radler, Dollie, Tulsa, Okla.
Rath, Charles M., Denver, Colo.
Rees, Forest R., Tulsa, Okla.
Reeves, John R., Oil Hill, Kan.
Renaud, Charles L., Cisco, Tex.
Reynolds, Roy A., Independence, Kan.
Rich, John L., Ottawa, Kan.
Richards, A. H., Tulsa, Okla.
Richards, J. F., Ardmore, Okla.
Ridgeway, B. S., Independence, Kan.
Rife, Byron, Independence, Kan.
Riggs, R. J., Tulsa, Okla.
Roark, E. L., Ponca City, Okla.
Roark, Louis, Okmulgee, Okla.
Roark, Ralph B., Marland, Okla.
Roberts, Morgan E., Mexia, Tex.
Robinson, B. F., Tulsa, Okla.
Robinson, Heath M., Dallas, Tex.
Rogers, Reese F., Washington, D. C.
Rollin, G. S., Tulsa, Okla.
Romine, Thomas B., Denver, Colo.
Roop, Charles W., Bartlesville, Okla.
Rothrock, E. P., Vermillion, S. D.
Rothrock, H. E., Tulsa, Okla.
Row, Charles H., San Antonio, Tex.
Rubey, W. W., Washington, D. C.
Ruby, Glen M., Denver, Colo.
Russell, William L., Vermillion, S. D.
Russom, Vaughn W., Bartlesville, Okla.

Sale, Clarence M., Ponca City, Okla.
Sammons, George B., Toronto, Can.
Sawtelle, George, Houston, Tex.
Schilling, Karl H., Okmulgee, Okla.
Schlosser, P. A., El Dorado, Kan.
Schneider, H. G., Shreveport, La.
Schnurr, C., Tulsa, Okla.
Schoolfield, R. F., Laredo, Tex.
Schramm, E. F., Lincoln, Neb.
Scott, H. M., Bartlesville, Okla.
Scudder, E. W., Wichita, Kan.
Sealey, F. C., Houston, Tex.
Seitz, J. R., Billings, Okla.
Selig, A. L., Shreveport, La.
Severy, C. L., Tulsa, Okla.
Shannon, Charles W., Norman, Okla.
Shaw, E. W., New York, N. Y.
Shea, Edward F., Tulsa, Okla.
Sheldon, William W., Tulsa, Okla.
Shutt, R. E., Dallas, Tex.
Snider, L. B., Tulsa, Okla.
Snider, L. C., Bartlesville, Okla.

Snider, Wilson G., Tulsa, Okla.
Snow, D. R., Tulsa, Okla.
Stacy, Dean M., Oklahoma City, Okla.
Stathers, S. C., Shreveport, La.
Stephenson, C. D., Tulsa, Okla.
Stewart, Hugh A., Denver, Colo.
Stewart, Irvine E., Denver, Colo.
Storm, W. W., Jr., Wichita Falls, Tex.
Straub, Charles E., Wichita, Kan.
Stryker, William L., Fredonia, Kan.
Studt, Charles W., Independence, Kan.
Suman, John R., Houston, Tex.

Tarr, Russell S., Tulsa, Okla.
Taylor, C. B., Winfield, Kan.
Taylor, Charles H., Oklahoma City, Okla.
Teas, L. P., Shreveport, La.
Teas, Paul C., Norman, Okla.
Tester, Allen C., Madison, Wis.
Thom, W. T., Jr., Washington, D.C.
Thomas, C. R., Tulsa, Okla.
Thomas, J. Elmer, Chicago, Ill.
Thompson, T. C., Bartlesville, Okla.
Thompson, Wallace C., Wichita Falls, Tex.
Thralls, W. H., Wichita, Kan.
Tillotson, Harold H., Latham, Kan.
Tomlinson, C. W., Ardmore, Okla.
Trager, Earl A., Ponca City, Okla.
Trout, L. E., Wichita Falls, Tex.
Truex, Arthur E., Tulsa, Okla.
Twenhofel, W. H., Madison, Wis.
Tygrett, H. V., Dallas, Tex.

Umpleby, J. B., Norman, Okla.

Valerius, M. M., Tulsa, Okla.
Van der Gracht, W. A. J. M., Houston, Tex.
Van Gilder, H. R., Tulsa, Okla.
Van Tuyl, F. M., Golden, Colo.

Walker, Lucien H., Tulsa, Okla.
Walker, W. L., Denver, Colo.
Waring, G. A., Tulsa, Okla.
Warner, C. A., Okmulgee, Okla.
Waters, James A., Norman, Okla.
Watson, J. D., Tulsa, Okla.
Weeks, H. J., Dallas, Tex.
Wegemann, C. H., Denver, Colo.
Weidman, S., Norman, Okla.
Weinzierl, John F., Houston, Tex.
Weirich, T. E., Tulsa, Okla.
Wells, S. W., Okmulgee, Okla.
Welsh, L. G., Tulsa, Okla.
West, J. Warlick, Purcell, Okla.
Whitcomb, Bruce, San Angelo, Tex.
White, David, Washington, D. C.
White, Luther H., Tulsa, Okla.
Whitehead, R. B., Dallas, Tex.
Whitney, Paul A., Tulsa, Okla.
Williams, Francis, Tulsa, Okla.
Wilshire, L. M., Blackwell, Okla.
Wilson, Roy A., Norman, Okla.
Wilson, W. B., Tulsa, Okla.
Winter, N. B., Shreveport, La.
Wohlford, Charles J., Houston, Tex.
Wolf, Albert G., Gulf, Tex.
Wolff, D. J., Wichita Falls, Tex.
Wood, Robert H., Tulsa, Okla.
Wood, Virgil O., Tulsa, Okla.
Woodruff, E. G., Tulsa, Okla.
Wrather, W. E., Dallas, Tex.
Wright, Harry F., Tulsa, Okla.
Wyman, E. A., Tulsa, Okla.

Yoakam, C. A., Holdenville, Okla.
Youngs, L. J., Eureka, Kan.

RAYMOND C. MOORE

TENTH ANNUAL BUSINESS MEETING OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, WICHITA, KANSAS, MARCH 26, 1925, JAMES H. GARDNER, PRESIDING

REPORT OF THE PRESIDENT

When I was honored a year ago with the presidency of the Association, there was turned over to me an efficient and smoothly running organization which it has been my earnest endeavor to perpetuate during my term of office. The year has demonstrated that the Association is still advancing. Its membership is steadily increasing and it is reaching out into a larger sphere of usefulness. It is entering new channels of service; growing in its being recognized as a scientific and educational institution in addition to its application in the field of economics. It is held in splendid favor by the oil fraternity and the public. The Association is one of solidarity and unity of purpose. In this connection I am pleased to include officially a quotation from a letter received from Dr. John M. Clarke, in which he writes, among other things, as follows: "I am quite within the truth in saying that there is not in the world another body of such magnitude and efficiency engaged upon a special aspect of applied geological science as is this Association."

The standing of the Association is due to the momentum which you as individual members have given it through your support and enthusiasm. There is a fine spirit of fellowship and co-operation here which means that differences of opinion are easily ironed out and varying views of policy easily adjusted and determined. Correspondence between the officers, committeemen, regional directors, and general membership is promptly executed. My predecessor took a great deal of pride in telling me a year ago at Houston that letters were very quickly answered in the Association, no matter to whom they were sent, and that various requests were promptly executed. I have found such to be the case, which all the more speaks for interest and efficiency within the body of the Association membership. Let us highly resolve that this spirit be kept up and that we capitalize the Association on the asset of friendship and co-operation.

Not everything can be done in any one year. Any particular year's work is determined materially by the year that preceded it, and much that is done in any one year is to a degree the outgrowth of movements previously initiated. Thus the credit of the Association's development runs in reverse order back to the initiatory stages. During this year, the Executive Committee has been doing the best it could to carry ahead and complete the policies inherited from the past administration and to initiate new ones and start them on their way to further execution by those whom you select to follow us. An organization, like an individual, when it ceases to grow will begin to deteriorate. It should build up new tissues, attack new problems, and enter additional fields of endeavor just as our Association has been doing from its beginning. A certain degree of patience is required along with persistence and determination in order ultimately to arrive at success on some of the major problems.

The principal steps taken by the Executive Committee during the year are as follows:

1. The publication and distribution among the membership of the code of ethics adopted the preceding year.

2. The publication in trade journals of articles setting out what the Association stands for, with stress on ethical standards and calling attention to the fact that the petroleum geologist is not "a freak" but a substantial citizen engaged in an important part of the oil business.

3. Co-operation in the organization of our membership on the Pacific Coast in the formation of the Pacific Society of Petroleum Geologists.

4. In lieu of a mid-year meeting, the attendance and entertainment of the Association at the International Petroleum Exposition.

5. The attendance of a number of our members at the annual meeting of the American Petroleum Institute at Fort Worth.

6. The recommendation of a careful scrutiny of the large number of applications for membership and dropping from the rolls the few who are not sufficiently interested to pay the annual dues.

7. The encouragement of more applications from qualified petroleum geologists of other countries, with the filling of a growing demand for our *Bulletins* in foreign libraries.

8. A continuation of the wise policy established last year for investment of Association funds in grade A scecurities.

9. The securing and publication of abstracts of papers in connection with the program of the annual meeting.

10. The initiation of a research fund with the acquisition of sufficient donations to carry out a particular project and further steps, as included in the report of the chairman of the Research Committee.

1. The publication of the code of ethics has met with favorable response on the part of the members. I have personally seen it hanging in most of your offices I have visited. The pride in which it is held means volumes for the attempt to live up to its standards.

2. The publication of articles in the petroleum magazines of the country in explanation of the purposes and ideals of the Association has induced favorable comment and has helped to sow the seeds of higher regard on the part of the operators and the public generally. On all occasions possible we have attempted to bring out the fact that the petroleum geologist is engaged in a worthy vocation and is in most cases a dependable and useful citizen. We wish to encourage among our members an increased activity in the civic and business affairs of the localities in which they are domiciled, in order that they may keep away from the viewpoint that their calling is in any sense a peculiar or isolated one. Meet your executives or clients in a spirit of business-like co-operation, with neither a spirit of superiority nor inferiority in your personality, but as one who is doing an integral part of the undertaking at hand. Adopt a spirit of personal fellowship with your business associates in order that you may be of service on matters of plans and policy, to the end that your work may be of greater service. The term "rock hound" as applied to the geologist, although

used in a spirit of fun, might well be resented by those men and women who devote their energies and study to the conditions under which oil is found and recovered. The classification of lands as favorable and unfavorable territory is the first important basis on which oil prospecting rests, and the utilization of subsurface data as development progresses determines the proper and wise expenditure of millions of dollars in the industry. There are "leasing hounds," "drilling hounds," "operating hounds," and "financial hounds" all running in a great pack to supply the fuel on which the prosperity of the nation depends. The geologist is called on by the industry to lead off on the trail and be there after the digging is under way in order to smell out the ramifications of the underground lair. He is not the only hound that runs sometimes on a hot trail and sometimes on a cold one. However, he knows the "foxy" country, and failing to find the game in one hole, he traces him to another with reasonable success in the end.

3. The Pacific Coast Society of Petroleum Geologists, organized during the year with the co-operation of our vice-president, includes members of the A.A.P.G. only. They are working in a spirit of splendid harmony and organized for the one object of carrying out the purposes and aims of the Association. They are so located that they have a goodly number in a definite geographic province, and their getting together will undoubtedly mean solidarity of the Association in their territory. We encourage them to bear in mind the importance of the annual meeting as a place for personal contact and for delivery of important papers, and the Association *Bulletin* as the medium for publication.

4. The fall gathering of the Association at the Petroleum Exposition in Tulsa was well attended. It proved to be a profitable experience for many members who came from all sections of the United States. The size of the exposition was a surprise to many, and a study of the various exhibits proved a schooling in itself well worth while. The Tulsa members of the Association looked after the housing and entertainment of the visitors. The Executive Committee and the Research Committee held important meetings at that time. The banquet held at the Oakhurst Country Club on that occasion, with accompanying "stunts," much resembled our annual banquet, both in spirit and size of attendance. In fact, the sentiment engendered in the membership by that splendid meeting at Houston, a year ago, has carried through the year and still echoes from the walls at Wichita.

5. A number of our members attended the annual meeting of the American Petroleum Institute in Fort Worth, at which time the second meeting of the Research Committee of the A.A.P.G. was held. The Association is honored by having one of its ex-presidents as director of the A.P.I., and we wish to urge a fuller attendance of our members at the Institute meetings. We should have a larger number of our members as members of the one big American organization which includes all branches of the oil industry. Here you form a closer contact with the operators, refiners, and marketers. The Institute has every reason to

expect you there and wishes to encourage your participation. One of your members who is affiliated with the Institute made a splendid and sensible address at the Fort Worth meeting on the value of petroleum geology to the industry. Join the American Petroleum Institute and make your plans to be present at the next annual meeting. There is no evil nor perverse motive in that organization, but on the other hand it is founded on an earnest policy of promoting the welfare of the oil industry on a basis of justice and equity for all concerned.

6. During the year, and previous to the meeting, the Executive Committee has received and passed on 185 applications for full and associate membership, a new member every two days in the year. Several have been rejected for lack of qualifications. We have no available record of the number who have desired entrance but who have not been able to secure the three necessary indorsers. In this connection, we urge careful consideration of the applicant before indorsement by signature on the application, on account of the fact that the Executive Committee feels an embarrassment in rejecting an applicant after indorsement by active members in good standing. Some members are elected on the authority of the Executive Committee, due to the experience or standing they have acquired in lieu of university training, in accordance with Article 3 of the constitution. Here the Executive Committee has a broad leeway to include a complex and varied type of experience which cannot well be put down in the form of a definite written rule. Several petroleum engineers have in previous years been admitted under this provision, and a number of them applied and were admitted this year, since it is felt that their work is clearly affiliated with our own, and, in fact, a considerable number of our members elected as petroleum geologists are actually now engaged in petroleum engineering. It seems as if the line cannot be definitely drawn between the geologist and petroleum engineer.

During the year we have dropped a few members for non-payment of dues. They can be reinstated, in cases where injustice may have been done due to mitigating circumstances later brought to the attention of the Committee. The Executive Committee recognizes that they carry considerable responsibility in the electing of members so long as a unanimous approval by the entire membership is not received.

7. The secretary and editor report an increased demand for our *Bulletin* by libraries of this and other countries. Our membership includes a considerable number of petroleum geologists from across the borders and the seas. During the year applications have come to us and elections have been made of men from nearly every country in which oil is being produced. We have encouraged their applications on account of the broadening of our Association to one of international character, and looking forward to a general meeting to cover foreign fields, in which we wish to invite participation of the men best qualified to cover the fields in which they are personally experienced.

8. The treasurer's report will show that expenses of the Association, especially the cost of the *Bulletin*, increase with our growth, so that the funds available

for investment from present size of dues is constantly decreasing. We have continued the policy of keeping funds invested in safe securities. The time must come, however, and is not far distant, when we must increase our income or begin to draw on investments in order to keep pace with growth.

9. We have adopted this year the plan of securing abstracts of papers and publishing them with the program at the annual meeting. In addition to furnishing this information for the members in attendance, we believe it will lead to a feeling on the part of the author that he can shorten the time required for delivery of his paper by giving the essentials of his theme without encroaching too much on the time of those who follow on the program. The delivery of the papers at the annual meeting within the time allotted is a problem of some magnitude, and we are striving, if possible, to keep away from the necessity of group sessions.

10. During the year, the Research Committee advanced the cause of research by meetings, discussions, and correspondence wherever and whenever possible, with the securing of some headway. General plans are still in the making for more important moves to follow, as will be outlined by Mr. Wrather. We find the subject of research is in the minds of individuals, government officials, and corporations everywhere, with definite moves on the part of certain oil companies in the establishment of research funds of their own. There are many cross-currents of the plans of research, but it is believed that eventually the Association will be called on to assist in the solving of important problems which the corporations will consider of general interest and value for all and should be done through particular groups at specified places.

A definite problem came to the attention of our Research Committee this year with both the equipment and the personnel available for its immediate prosecution. This was the matter of "experiments to prove the origin of oil," made available by David White, of the National Research Council. The amount of funds necessary to carry on the work was not excessive, with the result that our Research Committee secured donations from a few members of the Association sufficient to complete the funding of the project. This was a definite move to attempt the solution of a special problem, with the prospects of interesting and valuable results. It means the Association has taken its first step in the matter of financially assisting research, and the ultimate ends to be met will depend on the opportunities that may open up on the future as the whole question becomes clarified. The appropriation by individuals or corporations, or a combination of the two, yielding a material sum of money for the prosecution of research on certain phases of petroleum geology of value to all concerned, would undoubtedly mean that the Association would be called into assistance in helping to direct the work. The fact that we are ourselves showing good faith in the promotion of research is timely and will redound to the credit of the Association. It has not been our attempt or plan to impose any undue burden on the Association, but merely to suggest that we must move "upward then and onward to keep abreast of truth."

In closing, permit me to express the same sentiments as did my predecessor in appreciation of the loyalty, friendliness, and co-operation of the Executive Committee, regional directors, and membership generally; to thank my associates of Tulsa, who have assisted in every way possible, particularly in the splendid way they handled the arrangements and program of entertainment at the Petroleum Exposition last October; and to express to the boys here at Wichita the appreciation, not only of the Executive Committee, but of the Association at large, for the excellent way in which they have arranged to make this meeting a success. Those here who have worked hardest, have done so with no thought of personal publicity nor credit to themselves, but seized the opportunity as one of service above self. This spirit is characteristic of the Association in its various localities and groups.

I too have enjoyed the job you gave me and will pass it on to my successor with a resolution to assist in keeping the Association up to the standards which make membership in it a joy and a satisfaction to you and to me.

Respectfully submitted,

JAMES H. GARDNER

REPORT OF THE SECRETARY

At the ninth annual meeting last year in Houston, a vote was taken favoring the incorporation of our Association. At that time there were 1082 members. Of these, 802 have signed the slips consenting to transfer from the unincorporated to the incorporated Association. This leaves 280 who were members at that time who have not yet signed the transfer slips. Max Ball arranged for the incorporation in Colorado and for the domestication in Oklahoma, Charles H. Taylor having been appointed our agent in Oklahoma. In both the incorporation and domestication, Mr. James R. Jones, of Cheyenne, Wyoming, handled the legal phase without expense to the Association.

Membership of the Association:

Number of members May 19, 1917 (first published list)	94	
Number of members March 15, 1919	210	
Number of members March 22, 1924	1080	
Number of active members March 20, 1925	935	
Number of associate members March 20, 1925	318	
Total number of members March 20, 1925		1253
Applicants elected, dues unpaid	65	
Applicants approved for publication	45	
Recent applications	37	
Total applications on hand		147

Number of members withdrawn	8	
Number of members dropped	28	
Number of members died (honorary)	1	
Number of members in arrears, 1923 dues	2	
Number of members in arrears, 1924 dues	40	
Active members in arrears, 1925 dues	203	
Associate members in arrears, 1925 dues	63	
Total members in arrears, 1925 dues		266

Distribution of publications:

1. Subscriptions		
Libraries (domestic, 71; foreign, 6)	77	
Companies (domestic, 31; foreign, 14)	45	
Individuals (domestic, 55; foreign, 15)	70	
Total subscriptions		192
2. Exchanges, etc		10

Respectfully submitted,

Charles E. Decker, *Secretary*

Report of the Treasurer: Statement of Receipts and Disbursements, March 20, 1924, to March 18, 1925

Balance on hand in banks at March 20, 1924 (Auditor's Report)			$ 5,523.29
Receipts for fiscal year:			
Associate dues	$2,268.00		
Full membership dues	9,823.00	$12,091.00	
From Bulletin:			
Subscriptions	1,600.10		
Sales of bound copies	152.00		
Sales of back numbers	1,629.07	3,381.17	
Miscellaneous:			
Advertising	927.86		
Separates	100.00		
Interest	675.20		
Unclassified	7.03	1,710.09	
Received from Union Trust Co., Denver, Colo., repayment on investment (Wyoming Farm Land Loan)		1,259.02	
Total receipts for fiscal year			18,441.28
Total funds handled for fiscal year			$23,964.57

DISBURSEMENTS:

Editor's office:		
Editor's Salary	$ 600.00	
Secretarial work	300.00	
Postage	45.80	
Telegrams	21.49	
Ethics code	146.91	$ 1,114.20
Advertising manager's office:		
Postage		8.00
Editorial secretary's office:		
Salary	671.80	
Postage and Supplies	34.30	706.10
University of Chicago Press:		
Printing Bulletins:		
Vol. VIII, No. 1	947.96	
Vol. VIII, No. 2	1,114.32	
Vol. VIII, No. 3	1,100.60	
Vol. VIII, No. 4	1,040.86	
Vol. VIII, No. 5	1,098.63	
Vol. VIII, No. 6	1,409.35	6,711.72
Extra binding and printing	504,68	
Reprints	464.84	
Stencil corrections and mailing	290.71	
Shipping Vol. VII	106.01	1,366.24
Total expense of publication		$9,906.26
Expense of general office:		
Secretary-treasurer's salary	900.00	
Secretarial help	774.80	
Printing (code of ethics included)	462.94	
Postage	297.73	
Supplies	100.16	
Drayage	2.94	
Exchange and refunds	14.00	
Protested checks (all made good)	95.78	
Unclassified	21.05	2,669.40
Expense of Houston meeting:		
Expense of secretarial force	155.06	
Clerical help	29.80	
Badges	43.50	228.36
Carried forward		$12,804.02

Brought forward		$12,804.02
Executive Expense:		
Incorporation papers	2.50	
Telegrams	73.00	
Domestication of A. A. P. G.	14.00	89.50
Expended for interest-bearing bonds International Trust Co., of Denver, Colo. (see Schedule attached)		6,061.49
Total disbursements for fiscal year		$18,955.01
Unexpended cash on hand (see Schedule)		5,009.56
TOTAL		$23,964.57
Cash on hand at March 18, 1925	$5,009.56	
Investments at March 18, 1925 (see Schedule)	17,400.00	
Total in hands of treasurer		$22,409.56

Schedule of expenditures for bonds during fiscal year:

Anaconda Investment Bonds	$ 978.33
Northern States Power Co.	1,022.25
Pondera County Bonds	1,022.61
Nevada California Electric Bonds	3,034.00
Expense of buying	4.30
Total carried to disbursements	$ 6,061.49

Schedule interest-bearing bonds and investments at March 18, 1925:

United States Treasury Certificates	4,100.00
Wyoming Farm Loan	800.00
Northern States Power (6 per cent)	1,500.00
Imperial Japanese Bonds (6½ per cent)	500.00
Nevada California Electric Bonds (6 per cent)	5,000.00
Anaconda Copper Co. (6 per cent)	1,000.00
Wilson & Co. (6 per cent)	1,000.00
Pandera County Bonds (5½ per cent)	1,000.00
Hardin County, Texas, Bonds (5 per cent)	1,000.00
St. Louis and San Francisco Ry. (5 per cent)	500.00
United States Rubber (5 per cent)	1,000.00
Total interest-bearing bonds and investments	$17,400.00

Bank reconciliation at March 18, 1925:

Balance as per bank statement, Security National Bank, Norman, Okla., March 17, 1925		$2,558.48
Outstanding checks, No. 98	$8.00	
102	1.32	
103	1.00	10.32
Book balance		$2,548.16
Balance as per First National Bank, Norman, Okla. (no outstanding checks)		2,443.03
Balance in savings account, First National Bank, Norman, Okla.		18.37
Total unexpended balance as shown in statement		$5,009.56

(This report is in the form in which the accounts were audited by the D. C. Patterson Audit Company of Oklahoma City, A. E. Hill accountant in charge, who pronounced the accounts of the treasurer correct.)

Respectfully submitted,

CHARLES E. DECKER, *Treasurer*

REPORT OF THE EDITOR

The statements of the president expressing those cordial relations between the members of the Association and the Executive Committee, and particularly that which relates to the work in connection with its publication, may constitute an introduction to the report of the editor. A great deal of labor has been expended in the effort to carry forward and constantly improve the character of our publication.

We have included, beginning with this volume of the *Bulletin*, a short abstract of the papers at the head of each article. This is in line with the policy of some of the other bulletins, and has the advantage of enabling the busy man in the field to judge of the substance of the paper, and distribute his more detailed reading accordingly.

The size of the *Bulletin* is a matter of general concern and interest to the association. The Executive Committee has followed the policy in connection with publication of accepting and encouraging the setting down of observations made by members of the Association, including the younger members, and I think that much of the volume has resulted from that encouragement. The Association is increasing constantly in size, and perhaps we are reaching the point where closer scrutiny and more rigid selection of material may become necessary. There is now in type material approximately equal to twice the size of the number which has already appeared, and you have noticed that there has been a considerable increase in size. The matter of a monthly publication was considered, but the Executive Committee felt that it was not wise to

shorten the time of issue, for that demands still more editorial supervision. I do not know whether the Association at large wishes to instruct its editor, associate editors, and Executive Committee with reference to method and time of publication. A number of papers have been rejected, but most of those which have been received have found their way into our columns. The increased demand for the *Bulletin* is a satisfaction to us, and it must be to all of you. The cost, size of the *Bulletin*, and other improvements are the features which are perhaps particularly to be brought to your attention at this time.

Respectfully submitted,

RAYMOND C. MOORE, *Editor*

REPORT OF THE ADVERTISING MANAGER

The business of the advertising manager, as I conceive it, is to add to the revenues of the Association, to make possible more publication. As you can see from the report of the treasurer, the advertising manager has been successful in making enough to approximate one number of the Association *Bulletin*. When I took this job from Mr. Thomas, he held out no illusions as to what I was getting into. There are three types of advertising in the *Bulletin*. In the first place, we have professional cards, which you gentlemen so kindly contribute toward, and which I regard in the nature of a subsidy to the *Bulletin*. Some of the oil companies place advertising with the *Bulletin*, without any feeling on their part that they will add to the sales of oil in that manner. If any of you are connected with advertising managers who are having difficulty in getting rid of their surplus funds, I will be glad to make arrangements with them for advertising. The third kind is commercial advertising, which is hard to get, as the advertising manager has a hard time showing them that they get value received. Some I believe are getting it, and there are some I believe that we ought to get in that capacity. If any of you are expending a large amount for technical apparatus and can say a good word for the *Bulletin* in that capacity, it will certainly help the advertising manager in getting those gentlemen on our list.

Respectfully submitted,

WILLIAM E. HEROY, *Advertising Manager*

NEW BUSINESS

ELECTION OF OFFICERS

E. DeGolyer and R. S. McFarland were unanimously elected respectively as president and vice-president, and Charles E. Decker and Raymond C. Moore were unanimously re-elected respectively as secretary-treasurer and editor. These four, together with James H. Gardner, the retiring president, constitute the Executive Committee.

In response to a request for a speech, Mr. DeGolyer spoke as follows:

"It is hardly worth while to come around here for the very few and I hope extremely 'select words' I have to say at this time. I realize that this is a considerable position and I am quite overcome by the honor that you have done to me. I can say at the present time that I hope I may be able to carry on in the traditions of the Association and that I may merit the confidence that you have placed in me."

REPORT OF THE RESOLUTIONS COMMITTEE

WHEREAS, in the recent incorporation of the American Association of Petroleum Geologists, generous legal assistance was rendered by Mr. James R. Jones, of Cheyenne, Wyoming; now therefore be it

Resolved, by the American Association of Petroleum Geologists in its Tenth Annual Meeting that the Association does hereby express to Mr. Jones its sincere thanks for such assistance and manisfestation of good will; and be it further

Resolved, that the president and secretary of the Association transmit to Mr. Jones a copy of this resolution.

WHEREAS, the Tenth Annual Meeting of the American Association of Petroleum Geologists in the city of Wichita, Kansas, has been marked by most pleasant entertainment, and excellent and instructive program, and a splendid feeling of good will, and

WHEREAS, the members here assembled will retain happy memories of their reception and entertainment in the city of Wichita, Kansas; will diligently and advantageously apply the instructive and beneficial features of the various papers presented and the observations made on the field trip; and will always be inspired to conduct themselves in harmony with the traditions of the Association in recalling the splendid spirit that has been here manifest; now therefore be it

Resolved, by the members of the American Association of Petroleum Geologists assembled in their Tenth Annual Meeting at Wichita, Kansas, that the Association does hereby express and record its thanks and appreciation to all of those who have directly and indirectly contributed to make this meeting so marked a success, and more particularly the following:

The General Committee on Arrangements, its various subcommittees; Kansas members of the Association, and the Kansas Geological Society;

The members who with such diligence prepared the many excellent papers presented;

The operators and companies within the oil industry for their liberal and general attitude in permitting data and information compiled at great expense to be fully presented and freely discussed;

The various persons and organizations who contributed funds to facilitate the work of the General Committee on Arrangements and its various subcommittees;

The members of the Twentieth Century Club for entertaining the ladies of our organization;

The Elks' lodge for the use of its hall and building;

The many individuals and companies in this district who exhibited such splendid public spirit in furnishing automobiles for the El Dorado field trip, and particularly the Empire Company for the excellent luncheon served in the field;

The public press for its fair and sympathetic attitude in reporting the proceedings and activities of the Association; and be it further

Resolved, that the General Committee on Arrangements transmit and convey so far as is within its power the text of these resolutions to those herein above named.

Respectfully submitted,

JOSEPH JENSEN
ROSWELL H. JOHNSON
JOHN R. SUMAN
Resolutions Committee

REPORT OF THE GENERAL COMMITTEE

Recommended that the Executive Committee approve the petition of the Pacific Society of Petroleum Geologists to be recognized as regional section of the American Association of Petroleum Geologists, in accordance with provisions of constitution of the A.A.P.G., with proviso that no member may be admitted to or continue in this section unless he is a member in good standing in the A.A.P.G., and that the Association has prior right of publication of any papers submitted to said section. Recommended that name of said section be Pacific Section of the American Association of Petroleum Geologists.

Recommended that the treasurer be bonded at the expense of the Association.

Recommended that the Association hold a New York-Washington meeting in the late fall of 1926, and that the president of the Association appoint a committee for this meeting; this meeting to be a symposium on foreign geology.

Invitations received to hold next meeting in Washington, New York, New Orleans, San Francisco, Wichita Falls, Tulsa, Fort Worth, Tampico, and Mexico City. Recommended that representatives of the above cities be allowed the floor to present invitation from their cities, next Saturday, for a period of two minutes each.

The General Committee recommends to members of the Association to take a more active interest and participation in the affairs of the American Petroleum Institute.

Recommended that publication of the *Bulletin* be speeded up or the numbers increased so as to publish all papers on hand promptly, the manner in which this may be accomplished to be left to the Executive Committee.

Recommended that in view of the very considerable increase in the secretary's work and publication program of the Association, the Executive Committee be instructed to make a survey of the Association records and present facilities to take care of present and future work, and is authorized to make such changes in personnel and salaries as appear to be desirable. The Executive Committee is instructed to inaugurate within the limits of the financial resources of the Association a modern and complete system of records, files, accounts, and editorial supervision such as will meet the necessities and convenience of the members of the Association.

Recommended that dues be increased from $10.00 per year to $15.00 per year for full members, this increase to be effective January 1, 1926.

Recommended that associate members' dues be increased from $6.00 per year to $8.00 per year, this increase to be effective January 1, 1926.

Respectfully submitted,

Alexander Deussen, *Chairman*	H. M. Scott
E. DeGolyer	Frank S. Hudson
Luther H. White	Charles H. Taylor
W. E. Wrather	W. B. Wilson
R. S. McFarland	David Donoghue, *Secretary*

After some discussion, the recommendations and report of the General Committee were adopted by vote of the Association.

Mr. E. G. Woodruff extended an invitation to hold the next meeting in Tulsa.

Mr. T. W. Hoffer extended the invitation of Fort Worth to hold the next meeting there.

On motion of W. C. Mendenhall, it was voted to send the following telegram to Dr. Charles D. Walcott on his seventy-fifth birthday:

Dr. Charles D. Walcott, Smithsonian Institution, Washington, D.C.:

The American Association of Petroleum Geologists at its tenth annual meeting sends to you greeting and congratulations from five hundred members present in profound recognition of the splendid service you have rendered to the geological sciences throughout a long, inspiring, and impressive career. We accord you our highest esteem and send this as a birthday greeting to assure you that no geologist can ever be unmindful of your labors and achievements and also as a wish that there may still be in store for you many other birthdays each with added luster and content.

James H. Gardner, *President*

In response to this telegram Dr. Walcott wrote President Gardner as follows:

Dear Mr. Gardner:

I thank you, and through you the American Association of Petroleum Geologists, for your birthday greeting and for your appreciation of the service that I have been

able to render in the various positions which I have happened to occupy during the past thirty-five years.

The work has always given me great pleasure and I still enjoy the daily routine of executive work at the Smithsonian and the occasional hours that are available for reading and research. I should like to renew my youth and carry on for the coming fifty years, but that is not Nature's way of doing things, so I am content to feel that others will go on far better than I could with the work in which I am so deeply interested.

With keen appreciation of the kind expression in your message, and with all best wishes for the future of the Association and its individual members,

Very truly yours,

CHARLES D. WALCOTT

On motion, the tenth annual business meeting of the association was adjourned.

CHARLES E. DECKER, *Secretary*

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma.

(Names of sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

George W. Artman, Ponca City, Oklahoma
Warner Newby, J. M. Armstrong, Glenn C. Clark
Harry J. Brown, Tulsa, Oklahoma
Sidney Powers, Alexander Deussen, A. L. Beekly
Murel E. Carpenter, Oklahoma City, Oklahoma
R. A. Conkling, L. E. Trout, W. C. Kite
William L. Clark, Bartlesville, Oklahoma
F. L. Aurin, Luther H. White, Alex McCoy
Walter F. Eastman, Lahore, India
D. Dale Condit, Frank B. Notestein, Robert Anderson
James Brian Eby, San Angelo, Texas
David White, W. T. Thom, Jr., K. C. Heald
Merwin G. Edwards, Los Angeles, California
Roy R. Morse, F. S. Hudson, E. F. Davis
Emmett R. Elledge, El Dorado, Kansas
Erasmus Haworth, A. W. Duston, H. M. Scott

Alfred R. Eyrrell, Wichita Falls, Texas
  Roswell H. Johnson, Walter J. Allen, Charles V. Millikan
M. Gordon Gulley, Ponca City, Oklahoma
  F. L. Aurin, David White, K. C. Heald
Paul P. Goudkoff, Los Angeles, California
  Willard W. Cutler, Jr., V. E. Swigart, Wayne Loel
Darsie A. Green, Tulsa, Oklahoma
  R. W. Clark, Louis Roark, A. W. Duston
Marcus A. Hanna, Houston, Texas
  W. F. Henniger, John R. Suman, David Donoghue
D. B. Hunter, Bartlesville, Oklahoma
  H. M. Scott, J. M. Sands, D. R. Snow
Floyd Hodson, Maracaibo, Venezuela
  V. E. Monnett, C. M. Nevin, Dabney E. Petty
Maurice W. Grimm, Shreveport, Louisiana
  W. C. Spooner, H. W. Bell, W. E. Hopper
Lewis B. Kellum, Tampico, Mexico
  Walt M. Small, E. B. Stiles, William A. Baker, Jr.
Walter B. Lang, Washington, D.C.
  W. T. Thom, Jr., David White, W. C. Mendenhall
Walter W. Larsh, Wichita, Kansas
  Charles E. Straub, Marvin Lee, C. R. Thomas
Thomas W. Leach, Tulsa, Oklahoma
  Lawrence J. Zoller, V. H. Hughes, Harry H. Nowlan
Charles E. Meek, San Francisco, California
  G. C. Gester, F. S. Hudson, Roy R. Morse
Guy E. Miller, Los Angeles, California
  T. K. Harnsberger, Roy R. Morse, E. F. Davis
Albert E. Oldham, Houston, Texas
  Donald C. Barton, F. B. Plummer, R. H. Goodrich
Frank E. O'Neill, Taft, California
  John F. Dodge, Duncan M. Johnston, Homer J. Steiny
Frederick J. Pack, Salt Lake City, Utah
  Hugh D. Miser, Frank R. Clark, Joseph Jensen
Arthur H. Petsch, Tampico, Mexico
  Walt M. Small, E. B. Stiles, William A. Baker, Jr.
W. Armstrong Price, Houston, Texas
  Alexander Deussen, Wallace E. Pratt, David Donoghue
George B. Pritchard, Melbourne, Australia
  Alexander Deussen, John R. Suman, David Donoghue
B. Coleman Renick, Washington, D.C.
  W. C. Mendenhall, David White, Hugh D. Miser
Robert E. Rettger, Dallas, Texas

Frederic H. Lahee, W. H. Twenhofel, C. S. Corbett
Raymond Richards, New York City
Earl A. Trager, F. B. Plummer, C. W. Hamilton
Lloyd W. Stephenson, Washington, D.C.
David White, D. W. Ohern, W. C. Mendenhall
Lynn W. Storm, Dallas, Texas
Federic H. Lahee, Thomas H. Kernan, Charles H. Row
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H. W. Peabody, Harry F. Wright, Frank C. Greene
Henry E. van Aubel, Maracaibo, Venezuela
A. A. G. Schieferdecker, O. Dreher, F. A. A. van Gogh
Owen A. Winsor, Ponca City, Oklahoma
F. L. Aurin, E. L. Roark, W. M. Burress
Samuel H. Woods, Tulsa, Oklahoma
F. H. Lahee, A. W. Duston, C. A. Warner
Harold R. Woodward, El Dorado, Kansas
William L. Ainsworth, W. K. Cadman, George A. Forrester

FOR ASSOCIATE MEMBERSHIP

Horace M. Bayer, Norman, Oklahoma
S. Weidman, A. J. Williams, V. E. Monnett
Dale L. Benson, Wichita Falls, Texas
R. S. Knappen, M. M. Garrett, Archie R. Kautz
William J. Berrigan, Tulsa, Oklahoma
V. E. Monnett, Richard Hughes, A. L. Beekly
J. Marshall Brown, Norman, Oklahoma
A. J. Williams, H. C. George, Roy A. Wilson
Homer H. Charles, Garnett, Kansas
R. S. Knappen, C. S. Corbett, Edgar W. Owen
Roland L. Clifton, Norman, Oklahoma
S. Weidman, Charles N. Gould, V. E. Monnett
Charles A. Daubert, Wichita Falls, Texas
Roy A. Wilson, V. E. Monnett, A. J. Williams
Will F. Earl, Tulsa, Oklahoma
L. H. White, L. G. Keppler, Ray V. Hennen
James Fitzgerald, Jr., Bartlesville, Oklahoma
E. P. Hindes, Marvin Lee, William L. Ainsworth
Leo R. Fortier, Tulsa, Oklahoma
F. W. Bartlett, S. W. Wells, K. H. Schilling
James N. Gould, Houston, Texas
Donald C. Barton, F. B. Plummer, S. L. Mason
Philip B. King, Midland, Texas
Melvin J. Collins, Arthur C. Trowbridge, Clarence E. Hyde
Malcolm B. Kittredge, Tulsa, Oklahoma

A. A. Langworthy, L. W. Kesler, Rudolf Brauchli
Marvin E. Lyster, Norman, Oklahoma
V. E. Monnett, A. J. Williams, H. C. George
Russell L. McCullough, Ponca City, Oklahoma
Charles C. Hoffman, L. C. Snider, R. S. Knappen
Edward T. Merry, Wichita Falls, Texas
V. C. Perini, Jr., Robert N. Kolm, M. M. Garrett
Milton M. Mershon, Tulsa, Oklahoma
Luther H. White, A. F. Morris, Malvin G. Hoffman
Percy A. Meyers, Wichita Falls, Texas
L. E. Trout, C. D. Stephenson, F. L. Aurin
Charles A. Milner, Jr., Wichita, Kansas
Justus H. Cline, Everett Carpenter, George A. Forrester
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Claude N. Valerius, Tulsa, Oklahoma
Charles T. Kirk, C. R. Thomas, Marvin Lee
Holmes C. Wheeler, Norman, Oklahoma
A. J. Williams, V. E. Monnett, Roy A. Wilson
Joseph Zaba, Pittsburgh, Pennsylvania
Roswell H. Johnson, R. E. Somers, W. Irvin Moyer

FOR TRANSFER FROM ASSOCIATE TO FULL MEMBERSHIP

Glenn H. Bowes, Monrovia, California
W. W. Copp, Robert B. Moran, J. B. Case
Frederic G. Holl, El Dorado, Kansas
Russell S. Tarr, Marvin Lee, Alex W. McCoy
Junius Henderson, Boulder, Colorado
Thomas S. Harrison, Charles T. Lupton, E. Russell Lloyd

FOURTEENTH INTERNATIONAL GEOLOGICAL CONGRESS

The provisional list of topics for special discussion at the International Geological Congress to be held in Madrid, in May and June, 1926, as announced in the preliminary *Circular* by the Committee on Organization, is as follows:

1. The World's Reserves in Phosphates and Pyrites
2. Geology of the Mediterranean
3. Cambrian and Silurian Faunas
4. Geology of Africa and Its Relations to That of Europe
5. Tertiary Vertebrates
6. Hercynian Folds
7. Tertiary Foraminifera
8. Modern Theories of Metallogeny
9. Vulcanism
10. Geophysical Studies
    a) Their Application to Geology
    b) Necessity of Unification of the Gravimetrical Methods

The Committee, of which Señor C. Rubio, president of the Board of Mines and former director of the Geological Institute of Spain, is president, and Señor E. Dupuy de Lôme (of the Geological Institute of Spain, Plaza de los Mostenses 2, Madrid) is general secretary, is preparing an elaborate series of excursions to be held before, during, and after the Congress which are designed to cover considerable areas of Spain and which must appeal strongly to stratigraphers, structural geologists, paleontologists, physiographers, and mining engineers. Guidebooks are already in preparation.

DAVID WHITE

OKLAHOMA GEOLOGICAL SURVEY PUBLICATIONS

The Oklahoma Geological Survey announces the publication of the following bulletins and circulars, which on account of state law must be sold at the prices listed:

		Price	Postage
Bulletin 33	Geology of Love County, Oklahoma, by Fred M. Bullard	$0.50	$0.05
Bulletin 32	Geology of the Southern Ouachita Mountains of Oklahoma, by C. W. Honess	1.00	0.15
Circular 10	A Siluro-Devonian Oil Horizon of Oklahoma, by George D. Morgan	0.25	0.02
Circular 11	Arkose of the Northern Arbuckle Area, by George D. Morgan	0.10	0.02
Circular 12	Stratigraphic Position of the Franks and the Seminole Conglomerates of Oklahoma, by George D. Morgan	0.25	0.04

It is requested that, in so far as convenient, stamps be sent for postage. Requests for these publications should be sent to Charles N. Gould, director, Oklahoma Geological Survey, Norman, Oklahoma.

Extra copies of separates of the article on "Subsurface Stratigraphy of the Coastal Plain of Texas and Louisiana" are available from the office of the secretary at a price of twenty-five cents per copy, postpaid.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Announcement is made of the wedding of GLENN E. LASKEY and Miss Virginia Marie Davis, of Ruston, Louisiana, on March 19, 1925. Mr. Laskey is geologist with the Roxana Petroleum Corporation nad has been working lately in East Texas.

H. N. SPOFFORD, formerly geologist for the Marland Oil Company, is now engaged in consulting work at El Dorado, Arkansas.

F. P. SHAYES, recently in charge of geological work for the Houston Oil Company at Camden, Arkansas, is assisting in laying a pipe for the same company from Live Oak County, Texas, to Houston.

J. E. BRANTLY, of the Atlantic Oil Producing Company at Philadelphia, Pennsylvania, is on a sojourn in Mexico, watching the drilling of some company wells.

A. L. SELIG, paleontologist for the Atlantic Oil Producing Company at Shreveport, Louisiana, recently visited New Orleans on company business.

H. V. HOWE, head of the department of geology at Louisiana State University, Baton Rouge, has resumed his lectures in university extension work at Shreveport, Louisiana. The course now being followed will cover formations of Eocene and Oligocene time in the Gulf Coastal Plain. The first lecture of the spring term, beginning with the Claiborne formation, was given Friday night, March 20, at the Shreve Memorial, after the regular monthly meeting of the Shreveport Geological Society, under whose auspices the course is being held. For the convenience of the members of the class, Professor Howe will add a set of type fossils and correlation charts to the geological collection of the university branch museum in the offices of the supervisor of the minerals division of the state conservation department at Shreveport.

W. L. MILLER, of the Ramsay Petroleum Company, Oklahoma City, Oklahoma, was in Shreveport, Louisiana, in March, getting information on late development in the Smackover, Arkansas, field.

L. P. TEAS, chief geologist for the Humble Oil and Refining Company at Shreveport, Louisiana, recently made a special trip to examine Cretaceous type sections in east Texas and southwest Arkansas.

M. ALBERTSON is assistant to the production manager of the Roxana Petroleum Corporation at St. Louis, Missouri.

The Marland Oil Company of Texas recently moved its headquarters from Dallas to Houston. Association members connected with this organization are Dr. Waterschoot van der Gracht, president; Alexander Deussen, vice-president; C. E. Hyde, director in charge of geology; and W. R. Berger, chief geologist.

L. H. Freedman, geologist of Snowden and McSweeny Company, with headquarters in Burkburnett Building, Fort Worth, Texas, is a recent visitor to Houston. Snowden and McSweeny have been among the most successful operators in the Gulf Coast field.

E. K. Soper, with the Sinclair Exploration Company, who has been in Europe for the past eight months, has returned to New York.

E. Ganz has been appointed as chief consulting geologist and head of the Royal Dutch Shell geological mission in Northern Peru, with headquarters in Paita.

Charles H. Pishny, of the department of economics, Marland Oil Company, Ponca City, Oklahoma, was in Shreveport, Louisiana, in March, on company business.

F. J. Miller, in charge of geological work for The Texas Company at their Shreveport, Louisiana, office, visited his little daughter at Kansas City in March.

Worth W. McDonald, geologist for the Louisiana Oil Refining Corporation at Shreveport, Louisiana, spent part of his vacation with home folks at Clay Center, Nebraska.

J. O. Nelson, geologist in the Shreveport, Louisiana, office of the Dixie Oil Company, has been transferred, effective May 1, to the Chicago office of the company on the eleventh floor of the Standard Oil Company of Indiana Building.

A. F. Crider, chief geologist for the Dixie Oil Company at Shreveport, Louisiana, is again at his office after recovering from an attack of influenza.

R. F. Baker, chief geologist for The Texas Company at Houston, Texas, spent several days in the Shreveport, Louisiana, district in April.

Ben C. Belt, geologist of the Vacuum Oil Company, returned from Australia in March and is now at Houston, Texas.

The Marland Oil Company of Texas has headquarters in the Cotton Exchange Building, Houston, Texas. F. Park Geyer is president, Alexander Deussen and C. E. Hyde are vice-presidents, and W. R. Berger is chief geologist.

F. P. Plummer taught the course in petroleum geology at the University of Chicago during the spring quarter of this year.

John R. Suman has recently been appointed vice-president and general manager of the Rio Bravo Oil Company, headquarters Houston, Texas, vice E. T. Dumble, retired under pension rules.

BULLETIN

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